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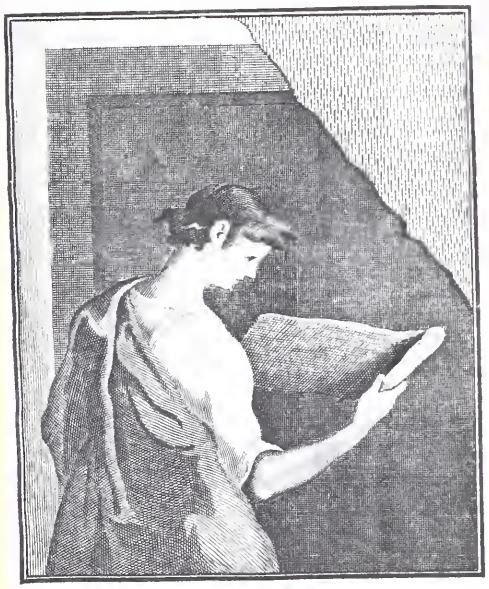

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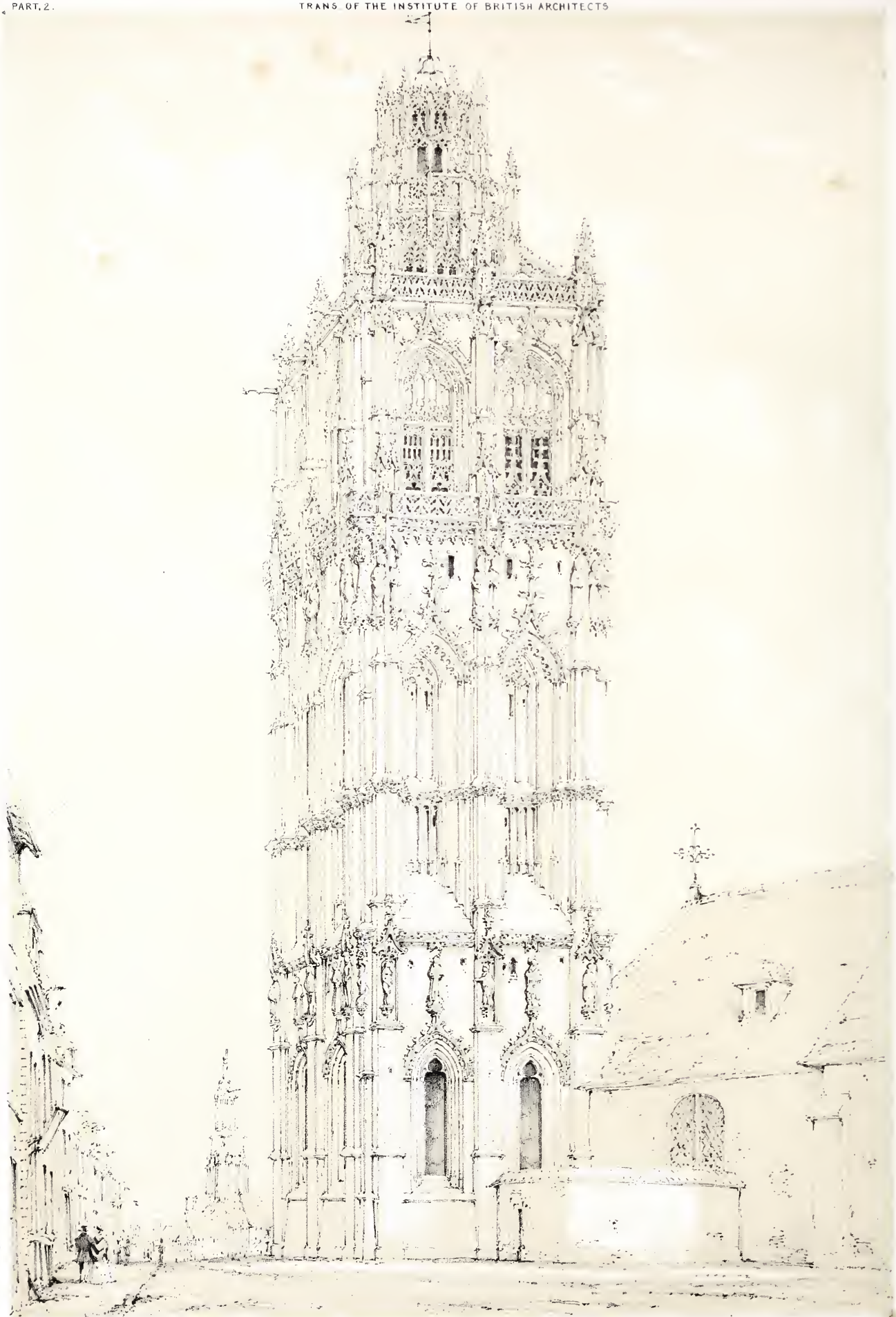

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1842.

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ERRATA.

Page 45, line 4, for c read *b*. Page 48, line 30, *for* to *read* be.

In pages 62, 63, 64, the term *versine* has been inadvertently applied to the horizontal distance M D (*fig.* B. p. 30) in all cases, whereas it is in strictness only applicable to it when the centre of the arch is upon the impost level. It must in these pages be however understood to mean the distance M D, whatever be the position of the centre.

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ON THE CONSTRUCTION OF THE VAULTS OF THE MIDDLE AGES.

BY R. WILLIS, M.A. F.R.S. &c.
JACKSONIAN PROFESSOR IN THE UNIVERSITY OF CAMBRIDGE, AND HONORARY MEMBER OF THE INSTITUTE OF BRITISH ARCHITECTS.

INTRODUCTION.

IN the year 1568, Philibert de l'Orme published at Paris his treatise on Architecture. This is the first work in which the art of masonic projection is introduced, and it contains a very complete essay upon that subject, which our author denominates the art of describing "*les traicts géométriques qui monstrent comme il fault tailler et coupper les pierres,*" and which in fact is the art of obtaining from the plans and designs of a proposed building the shape of the individual stones in a convenient form for the use of the mason. This first essay was followed by two works on the same subject by Maturin Jousse and Derand, which appeared nearly at the same time, namely, in the years 1642 and 1643. Other writers in France published upon this favourite subject, namely, Desargues in 1643, De la Rue in 1727, and Frezier in 1738. In fact, this has always been, and is now, a standard branch of architectural education in France, under the name of the "Coupe des pierres." It is joined with the corresponding art in carpentry, of which the first work was also written by Maturin Jousse, and published in 1627. In our own country this art has been rather neglected; our only writers are Halfpenny, "Art of Sound Building," 1725, and Nicholson, whose various works on this subject are too well known to professional men to need enumeration.

Now although the merit of reducing this art to written laws and systems, and thus of giving it a place in the literature of science, belongs undoubtedly to De l'Orme and his immediate successors already enumerated, it must not be supposed that he was the inventor of the art. On the contrary, the necessity for it plainly arose very early in the history of masonry. Indeed, De l'Orme never pretends to be the first inventor. His own language is that of a curious

pedant in his art, and he manifestly introduces many new methods and forms; but generally he talks of the matters which he is teaching as belonging to the ordinary practice of his age, which he is for the first time reducing to writing. It must be remembered, too, that the forms of the vaults which serve him for examples belong to the Italian style, and are very different from those of the Middle Ages; so that granting to him the merit of applying and modifying the old Gothic methods to adapt them to these new forms, it is plain that much of originality is due to him. He, like all his contemporaries, imagined his own architecture to be a genuine restoration of the ancient classical styles; and therefore he speaks of the Gothic vaults as "*voutes modernes que les maistres maçons ont accoustumé de faire aux églises et logis des grands seigneurs*" (p. 107). "Auiourd'huy ceux qui ont quelque cognoissance de la vraye architecture, ne suiuent plus ceste façon de voute, appellée entre les ouvriers La mode Françoise, laquelle véritablement je ne veux despriser, ains plustost confesser qu'on y a faict et pratiqué *de fort bons traicts et difficiles.*" Frezier also, speaking of Gothic vaults, says with great truth, "Toutes ces naissances entrelassées, et les intersections des moulures demandoient une grande intelligence dans l'Art de la Coupe des pierres; d'où je conjecture, que c'est à l'architecture *Gothique* que nous devons rapporter l'origine, ou du moins l'adolescence de cet Art. Ma raison est qu'outre qu'il ne nous reste pas de Monumens antiques où il ait été mis en usage que pour des traits assez simples, c'est que dans l'énumération que Vitruve fait des connoissances nécessaires à un Architecte, il ne parle point de celle de *la Coupe des Pierres;* en effet, la noble simplicité de l'Architecture des Anciens n'exerçoit pas beaucoup le sçavoir-faire des appareilleurs, qui n'avoient presque que des voutes cylindriques ou sphériques à conduire." (t. 1, p. xvii.)

It becomes, therefore, a curious and interesting subject of inquiry to trace, from an examination of the structures themselves, what geometrical methods were really employed in setting out the work, and how the necessity for these methods gradually arose. Independently of the value of such investigations to the history of the science of construction, the knowledge of the methods actually employed would greatly assist us in the imitation of the works of each period. For the forms and proportions of every structure are so entirely dependent upon its construction and derived from it, that unless we thoroughly understand these constructions, and the methods and resources which governed and limited them, we shall never succeed in obtaining the master key to their principles, and instead of *designing* works in the style of any required age, we must content ourselves with merely *copying* them.

The following paper must be considered as an attempt to sketch out an investigation of this kind, and in offering it to the body of practical men who are assembled in this Institute, I am not without hope that some of them may be induced to collect facts and examples by which this investigation may be carried on and completed. For it will appear, as we proceed, that most of the facts required are of such a nature that they can only be derived from the existing buildings by the aid of scaffolding, minute measurement, and close observation, which it is not often in the power of mere travelling observers to obtain.

Now professional men are so commonly entrusted with the repairs or restoration of these old structures, that if they would take the opportunity of making the required observations in every case where scaffolds were erected about a building, and if such observations were transmitted to the Institute, a few years would suffice to bring together a body of examples from which general rules might be deduced. It is only by comparing many examples that this can be done, for general rules deduced from single instances are commonly worthless.

Next to complete buildings under repair, Ruins afford the most valuable information upon construction. The best instructor of all, perhaps, is a building which is being pulled down, but such opportunities are always to be regretted. In ordinary cases, the upper surfaces of the vaults are so often covered with courses of rubble and concrete, rubbish and filth, and the lower surfaces with whitewash and paint, that when every facility has been obtained for examination, the jointing of the masonry and actual construction of the vault will still remain an unfathomable mystery.

Section I.—On the General Construction of the Vaults.

The ribbed vault of the Middle Ages, which is the subject of the present paper, differs entirely from the vaults of the Romans. It consists, as is well known, of a framework of ribs or stone arches, upon which the real vaults or actual coverings of the apartment rest. These vaults are usually constructed of a lighter material and with rougher workmanship than the ribs upon which they rest, and between which they constitute, in fact, a kind of thin pannel.

The construction of these ribs offers no difficulty in stone-cutting, each being, separately considered, a simple arch; nevertheless the forms of its voussoirs

can scarcely have been obtained without tracing on the ground the full-sized figure of this arch, from which to obtain the *face moulds* of the voussoirs.

However, in the Norman ribbed vaults the arches are so roughly constructed that it may be supposed that a small portion of the arch only was described and a single face mould employed for the whole, and that the joints of the voussoirs were not divided upon a complete full-sized drawing of the arch. We shall see, however, that this full-sized drawing was very soon required in the early English period.

Some of the Norman vaults are plain waggon vaults of rubble work as in the nave of the chapel at the Tower, or groined vaults of rubble as in the side aisles; but it is unnecessary to dwell upon these very early specimens, in which no difficulties either of stone cutting or of curvature are yet introduced[1]. It is only where the *groins* of the vault are supported by ribs that the branching of these ribs in various directions from one abacus, and the different spans of the transverse and diagonal ribs, introduce difficulties, which were at first, as might be expected, somewhat clumsily botched over or evaded, and which afterwards led to the invention of the geometrical system, the rise and progress of which it is my purpose to trace. In Norman ribbed vaults, however, each rib springs independently from the abacus, and appears to have been erected without any reference to the management of the incumbent vaults. The latter are formed of rubble and irregular work, and may probably, in some cases, have been packed together without centering[2], or at least with a very rude framework; and to accommodate the curvatures of the backs of the ribs, especially near the abacus where the ribs approach, these ribs are backed out where necessary with irregular stones and rubble work. There is an excellent example of this kind of vault in some apartments on the west side of the south transept of Peterborough cathedral. These have been long employed as mere workshops, and the surface of the vaults being denuded of plaster, if it ever had any, its construction is plainly shown. The compartments are covered with a cross-ribbed vault, of which the diagonal arches are semicircular, and the transverse pointed. The span of the latter is

[1] Of plain Norman waggon vaults, there are two excellent specimens at Norwich, one of them, under the Bishop's Palace, of about twenty feet span, supported at short intervals by subribs, plain and square edged, and resting upon semicircular plain corbels. A string cornice of the usual Norman profile runs along the impost line of the entire apartment, and is mitred round the corbels. The other specimen is an apartment on the south side of the nave of the cathedral at the west end, once probably the guests' hall, now the kitchen of a prebendal house.

[2] Vide an excellent paper by De Lassaux, on a mode of erecting light vaults. Journal of Royal Institution, vol. i. p. 224.

about thirteen feet. The voussoirs of the diagonal ribs are twelve inches square in the transverse section, and backed up, as already described, near the springing, so as to throw the spring of the vaults to a considerable height above the abacus. There are many other curious irregularities and peculiar forms in this vault, which is well worth examining.

Another good example is in the castle at Newcastle-upon-Tyne, in a large vaulted apartment about twenty-seven feet by twenty[3]. This has a central pillar, from which spring four transverse arches and four diagonal arches. Upon these the vaults rest. This is a very curious specimen, for every pair of these arches has a different span: that of the two transverse arches upon the long diameter of the room being twelve feet three inches each; of the two shorter transverse arches, nine feet; and of the diagonal arches, about fifteen feet nine inches.

All these arches are semicircular, and their crowns are all placed at the same level, to allow for which they are made to spring from different levels. *Fig.* 1 is a sketch of the springing of these arches from the central pillar. CD is one of the small transverse arches, which having the least span, springs from the highest point C. AB is one of the greater transverse arches, springing from A below the level of C, and EF, KL, GH, are diagonal arches, whose span being the greatest, spring from still lower points, E, K, and G, so that the crowns of all these arches rise to the same level. With respect to the voussoirs, it will be seen that although the backs or extrados of the voussoirs which constitute the arches are concentric to the soffits of these arches, yet these are backed up by a rude wall of rubble work, as at M, N and P, upon which the rough vaults are supported, and this is necessary to get rid of the difficulty of resting a vaulting surface upon arches whose curvature and level at the springing are so different.

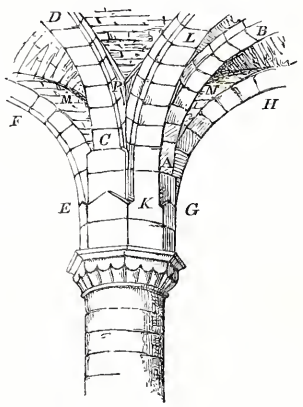


FIG. 1.

Fig. 2 is another example, which perhaps shows the nature of this difficulty more clearly. This is a portion of a vault from the ruins of Finchale Priory, in the county of Durham. AB CD are two ribs or arches which spring with very different curvatures from a single pillar. The vault is in this case formed of long thin stones, packed one upon the other, as shown at EFG. And as

[3] Accurate plans and sections, with details of this vault and of the castle, are in the Vetusta Monumenta. There are also some rough sketches in Carter's Ancient Architecture.

the different curvatures of the arches throw the surface at *f* much higher than that at *e*, the difference of level is made up by courses of rubble upon the lowest extrados of the two only between *e* and *m*, which are gradually thinned off at the latter point, and enable the stones of the vault to be laid straight from one arch to the other.

FIG. 2.

From these and many other examples it appears that in this early stage of rib vaulting the arches or ribs consist of independent and separate voussoirs down to the level course from which they spring, as in *fig.* 2, where A and C, *a* and *c*, are separate stones roughly jointed at the back, instead of being each got out of a single stone, as in the subsequent structures. Also the back or *extrados* of these ribs is concentric with the soffit, and thus formed without reference to the arrangement of the incumbent vault, which was plainly a subsequent and separate consideration; the ribs being, after their erection, backed out at the springing so as to accommodate the curvature of their *extrados* to the reception of the vault.

The vaults of the choir at Canterbury have in like manner their ribs formed of separate stones, from the abacus upwards, and backed up where necessary; the voussoirs of the ribs are also very small and numerous: I counted about a hundred in one transverse rib of the north-eastern transept in a span of thirty feet. These ribs are very richly moulded, but the workmanship is exceedingly rude.

To this rough construction of the spandrel succeeds all at once a more artificial structure, bespeaking a great advance in the art of masonry; and it is remarkable that this new construction once introduced remains with very slight change to the very latest period of rib vaulting.

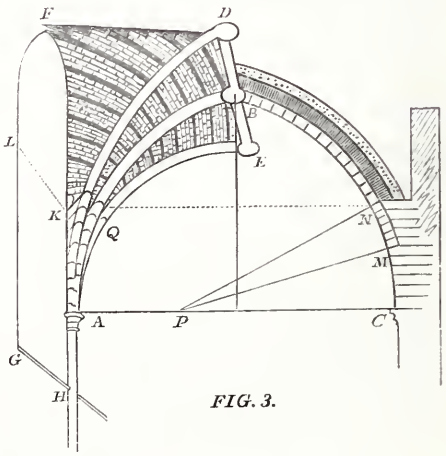


FIG. 3.

Fig. 3 is a diagram to illustrate this construction, and is principally derived from the south transept of Westminster Abbey, but is not drawn to scale. The left hand half of this diagram represents a portion of the vault in perspective, including the entire *spandrel solid* (if I may be allowed the expression), which is contained by the two semi-

diagonal ribs A D A E and the wall. A B C is the transverse rib, and on the right hand of the diagram the vertical section through this rib is exhibited. G H is the string moulding upon which the clerestory windows rest, and the arch which contains these windows springs from L K at a considerable height above the springing, A, of the vault ribs. This is a very universal arrangement of clerestory vaults, and is productive of great beauty and convenience, but it leads to some difficulty in the form and arrangement of the vaulting surface A K F D, for as this is contained between two arches or ribs, A D K F, which spring from different levels, it follows that this surface must be skewed back at K in a very peculiar manner. This is shown by the perspective. The junction of the solid mass, A K Q, with the clerestory wall is therefore bounded by parallel vertical lines, one of which is A K, and this mass is always built of solid masonry bonded into the wall and forming a part of it[4]. It is from the level of K Q that the real rib and pannel[5] construction of the vault begins, for separate ribs are erected upon the surface of this solid, and connected by vaults of a light material. From below, however, if the vault be painted and decorated, this change of construction at K Q is disguised, or, in other words, the decorative construction of the vault exhibits the rib and pannel from the abacus A upwards, but the mechanical construction is of solid masonry from A to Q, and of rib and pannel work only above this level. The point Q of this change of construction is commonly at about half the vertical height of the arch, as shown in the drawing, but is not necessarily at the same level as the impost K of the clerestory rib K F.

The peculiar construction of the solid mass A K Q is better shown in the section at C M N. The ribs of the vault converging downwards to C, their mouldings become entangled as it were, in a manner that will be subsequently explained. At a point M, about half way up the solid, they are, however, freed from each other, and separated by the divergence of the ribs. Now, between C and M the solid is built of horizontal courses of masonry, generally each

[4] This block of masonry appears to have been termed the *tas de charge*, for Philibert de l'Orme defines this term thus:—"Ce sont les premieres pierres que on voit sur les angles, et monstrent le commencement et la naissance des *branches, des ogives, tiercerons, formerets et arcs doubleaux*." These five terms are the names of the ribs, as we shall see presently.

[5] I employ the term *rib and pannel work* to distinguish that mechanical construction of the vaults of the Middle Ages, in which a frame work of ribs is made to support thin superincumbent vaults in the manner of pannels, from the vaults of solid masonry which were subsequently introduced, in which the stones are closely jointed throughout, and the ribs and pannels merely carved on their lower decorative surfaces. This latter system, which is in fact derived from the original Roman or earlier vaults, is wholly adopted in Henry the Seventh's Chapel at Westminster. But the two methods are, as will appear in the course of this paper, mixed together in the greater number of examples.

of a single stone, and its level beds cut the curved mouldings obliquely in front. Above M the ribs are each built separately of voussoirs, having their beds properly inclined to meet the axis of curvature P of the rib, and these ribs are backed and united by solid masonry which connects them with the wall, and which appearing between the ribs seems to be a portion of the light vaulting surface, such as is really employed higher up. From the upper surface N of the solid, each rib N B is still built as from M to N with voussoirs, but upon these ribs rests the light thin vault or pannel, shown in section on the right, and in perspective on the left of the diagram.

It is remarkable that the courses of the vaults are not laid level, but are in most cases made to incline downwards upon the diagonal rib.

Thus in *fig.* 3 the ridge F D is level, and also the ridge D B E; but the courses of the vaults incline considerably downwards from F K and from Q B towards the diagonal rib A D. These courses, in Westminster transepts, are of a light-coloured stone, probably chalk, interrupted, at regular intervals, by a course of a darker stone; and the ridge F D, which has no rib, is also formed entirely of this darker stone, laid in the serrated manner shown by the drawing. The dark courses are rather broader than the light ones, and there are four or five courses of the light between each of the dark. The surface F K D is also slightly concave or domical, and may therefore have been laid without any centering, since each course would support itself[6]. These peculiarities may all be found with some variations in other vaults of the same age.

What might have been the reason for this downward inclination of the courses it is not easy to say, but it is very common, especially in the earlier examples. Some have supposed it to have arisen from the courses having been laid to meet the bounding ribs A K F A D at respectively equal distances from their springing, which would certainly produce the effect in question, since the diagonal rib is so much longer than the others, but the downward inclination is greater than that which would arise from this cause. In some examples the slope seems to be derived from the courses having been laid so as to meet the diagonal rib at right angles. The perspective effect which arises from the arrangement is curious, for the vaulting surfaces A D B A B E are really very nearly coincident with a single surface extended from A D to A E, or in other words, a horizontal rod passed upwards along the backs of the ribs A D A E would very nearly touch the two vaulting surfaces and the back of the rib A B. But the effect of the inclination of the courses is to make the rib A B

[6] Vide the essay of De Lassaux.

appear in perspective as if prominent downwards from such a surface, and consequently gives to the entire solid spandrel F D E A the effect of a kind of fan vault or vault with a polygonal horizontal section.

Above the vaults are commonly laid a thick irregular course of rubble work, which again is also often covered with a coat of a kind of concrete. The vaults of Westminster Abbey, with the exception of the western compartments, those of Exeter, Winchester, Hereford (with the exception of the south transept and tower), Wells, Ely, Redcliff Church, Bristol Cathedral, and many others, are thus covered. These upper coverings appear to have been abandoned in the later periods, but not universally. Those of the western compartments of Ely choir seem to have been subsequently picked off, perhaps by Essex, to lighten the vault.

But the vaults of the western compartments of Westminster, and of the south transept and tower of Hereford, are left bare on the upper surface, and these vaults, instead of being built with small brick-like stones, are composed of long thin slabs. Also the ribs themselves are, in some later examples, formed of a few long bar-shaped voussoirs instead of the small and numerous pieces of the earlier examples. Thus in the transept of Westminster, N B consists of thirteen or fourteen stones, but at the west end of the nave, of six only.

The employment of the solid mass of masonry A K Q enables the ribs to approach more closely at the springing, and also reduces the actual span of the vault, for Q N is the real span of the vault, instead of A C, which is the apparent or decorative span. Thus about one-sixth of the span is saved.

The early ribs are formed as in *fig.* 4 (from St. Saviour's Church, Southwark), the vaulting surface resting only on their backs; but the later ribs are rebated for the reception of the vaulting surface, as shown in *fig.* 14, by which greater depth and strength is given to them without necessarily increasing their projection from the surface of the vault.

FIG. 4.

To return to the proper subject of this paper, namely, the evidences of a geometrical method in setting out the work: The solid spandrel from C to M, *fig.* 3, has been said to consist of level courses of masonry, and to contain all that portion of the vault in which the mouldings are entangled and partly concealed by the approximation of the ribs. Now two ways may be conceived in which these mouldings may have been worked out of the stone. The spandrel may have been built solid, and after the ribs M N were set up, the mouldings of the entangled ribs from M to C may have been worked gradually downwards,

first in block, and afterwards in detail, and in this way the various interlacings and interpenetrations of the mouldings would develope themselves as the workmen proceeded.

The other way would be to project geometrically upon each bed of the stones which constitute the spandrel from C to M the mouldings of each rib in its proper position, and thus would be shown which mouldings remained prominent and which were covered by others; and that this method was employed I shall shew from examples. Of course a perfect existing building affords no opportunity of examining the beds of its stones, but if the beds of a newly pulled down structure be examined by carefully scaling off the mortar, the mason's lines will be found to remain as freshly upon the surfaces as when they were first set up, and from these it will be seen that a complete geometrical method was used to obtain the intersections of the mouldings.

Fig. 6 is a plan of one of the spandrel stones, taken down from the side aisle vault of St. Saviour's Church, Southwark, in the course of its demolition, in 1839. This drawing is reduced to one-eighth of the original, and the lines and marks which it exhibits are carefully copied from those that were found upon the surface or bed. Upon this were traced lines parallel to the direction of the wall and of the several ribs of the vault respectively, as FG in the direction of the wall, AB for the transverse rib, AC and DE for the diagonal ribs. The vault to which this spandrel belonged was of an irregular plan, four-sided, but having each side of a different length, to accommodate which, one of the diagonal ribs DE is made to spring from a point a little removed from the intersection A of the other AC with the transverse rib AB.

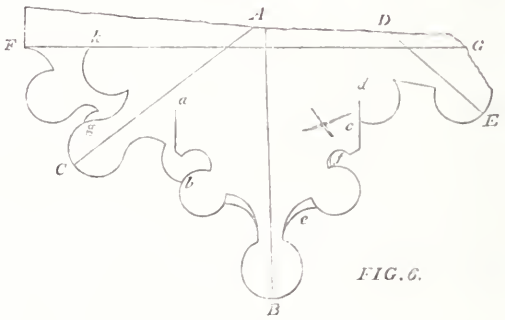


FIG. 6.

Upon each of these lines the profile, or as much as is required of it, of each rib is traced, evidently by means of a *templet*, that is, of a pattern of the rib cut out in some thin material, which was held down in its proper place upon the stone while its outline was scratched or cut by carrying some sharp-pointed instrument round its edge. Thus the first traced was manifestly the complete profile *a b* B *e f c d* of the transverse rib. Next, on the left hand side is the profile *b c g k* of the diagonal rib, and this by its projection obscures and renders unnecessary a portion *b a* of the former rib; and that this profile was

traced subsequently to the former one is plain by the omission of all that is covered by it to the right of *b*. The wall-rib *g* F was next traced, and this obscures the portion *g* K of the former rib. In like manner, on the right hand side, the profile *c* E was traced, obscuring the piece *c d* of the first rib. At G the stone is broken. The mouldings that were thus shown to project appear to have been then completely worked down to the outline thus obtained, excepting at one or two places, such as at *e* and *f*, where the trace of the templet still remains within the real edge of the bed.

The compartments thus vaulted in St. Saviour's side aisles were not rectangles but irregular trapeziums, and the diagonal ribs were slightly twisted upon the plan, as shown with some exaggeration in *fig.* 8. I have seen this in some other examples, but whether it results from design, with a view to dispose the branching ribs to better advantage, or from bad workmanship in not setting out the ribs in the *tas de charge* or solid block at the proper angles, and therefore making it necessary to warp their directions to enable them to meet at the crown, I am unable to decide.

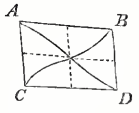


FIG. 8.

To draw these figures upon the beds of the stones, it is necessary to know in each case the quantity of projection of every rib, or, in other words, the points C B E to which the ribs extend at each joint, and against which the front of the pattern or templet must be placed before its outline can be traced. These are, however, so easily and obviously obtained by drawing on the full scale the elevation of each rib in its own plane, with the joints inserted after the manner of C M, *fig.* 3, that we may assume that this was the method employed.

A diagram of this kind is to be found both on the upper and lower bed of each stone, and the lines A, D, &c., which extend to the outsides of the stones, are scored vertically down the back for the purpose of making the two diagrams coincide. I may add, that every stone which I examined that had appertained to the spandrels exhibited similar lines and traces of mouldings; and as the pulling down of the buildings was proceeding during my examination, I had the opportunity of seeing the stones in their fresh state, and of myself scaling off the mortar.

The mouldings of these specimens are sufficient to show that they belong to an early period of the early English style. *Fig.* 7 is an example of a similar kind belonging to the Perpendicular period, and taken from one of the spandrels of a complex vault which formerly covered the extreme north-western compartment of the nave of Canterbury Cathedral, the lower story of the so

called Lanfranc's tower, which becoming ruinous, was taken down a few years since, and is now replaced by a modern copy of the south-western tower. The stones of the original vault, however, were carefully deposited in the nave of the cathedral and in the yard at the time of my visit, and I found the surfaces of these spandrel stones covered by lines and profiles of mouldings similar to those already described from St. Saviour's, showing that the same method had continued in use from the period of its first introduction.

The number of ribs that spring from each angle of this vault being seven, including the two wall ribs, made it necessary to employ two stones in each of its upper courses at least, and accordingly the bed represented in *fig.* 7, being only a portion of the entire spandrel, contains but four of these ribs. I have selected this one out of many others that I copied, because it is evident that a set of lines first drawn upon it were rejected because the stone was not large enough to contain the ribs, and another set was subsequently drawn and actually employed, which gives a somewhat additional interest to this example.

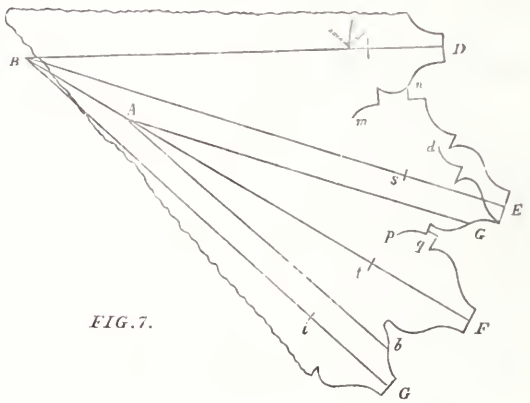


FIG. 7.

A *b* A G are the rejected lines, and *d* a portion of a profile of a rib belonging to A G. B D B E B F B G are the true lines, drawn each parallel to its own rib, as shown by the plan of the vault. The profile D *m* appears to have been the first drawn, then *n* E *p*, then *q* F, and so on. The marks at *s*, *t*, *i*, &c. are apparently for the purpose of distinguishing the true lines from the false ones. The average thickness of the courses in this spandrel is about ten inches.

As the beds of the stones are horizontal in all these cases, the upper beds necessarily cut the mouldings of the ribs at an acute angle or feather edge, and this sometimes occasions the edges of the stone to fly off. On the uppermost surface of these stones (as at M, *fig.* 3) every rib has its own slant bed provided and worked square to the plane of each elevation, so as to give a firm footing to the separate ribs that all start from this upper stone.

One consequence of thus allowing the bed of the stone to cut the arch line obliquely is, that the templet or pattern from which the mouldings are traced upon the bed becomes too short in the oblique section; for (*fig.* 5) if *m n s p t* be the upper stone, *m n* the bed from which the detached ribs start, and if

$m\,n$ be the transverse depth of the mouldings, then it is evident that on the lower bed $p\,t$ the depth of the same mouldings $p\,r$ will be considerably greater on account of the obliquity of the section. Now in the examples that I have examined, I found that the same templet had been employed to trace the mouldings upon $m\,n$, upon $p\,r$, and upon the other oblique beds below, and consequently these mouldings were drawn in and contracted very disagreeably, as shown by the dotted line $n\,q$, $p\,q$ being taken equal to $m\,n$. This is a curious proof of the rough neglect of minute circumstances by the Gothic masons of which plenty of other examples might be adduced, and it must be confessed that the false lines so produced are not perceptible from below. I believe we might in many cases reduce very considerably the expenses of our constructions if we had courage to imitate our ancestors in this respect. In the Canterbury example the angle $m\,p\,q = 110°$, and the depth $m\,n$ of the mouldings is five inches, consequently it may be easily calculated that $p\,q$ is half an inch too short; and the effect of drawing the point q half an inch out of its true place compared with ten inches, which is the thickness $s\,t$ of the stone, is very perceptible when the stone is looked at upon the ground, but when in its place aloft I have no doubt this error was perfectly unappreciable.

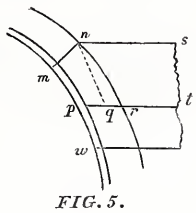


FIG. 5.

Section II.—On the Curvature of the Ribs.

The next set of examples which show the necessity of a geometrical system will be found in the construction of the intermediate ribs of vaults, and in the management of the curvature of the ribs generally. The limits of this paper will not allow me to enter fully into the description of the different classes of vaults in the decorative sense, neither is it necessary for my present purpose; I shall therefore briefly state the different steps by which they appear to have been led on from the simple cross-ribbed vault to the fan tracery. The plain cross vault, Roman in arrangement, but pointed and with the addition of ribs upon the groins, is to be found at Salisbury, Gloucester nave, Canterbury choir, Wells nave, Beverley, Westminster choir, and in all the French cathedrals. Simple intermediate ribs were first added between the wall ribs and diagonal ribs, and between the transverse ribs and diagonal ribs. Thus, in *fig.* 9, a vault with intermediate ribs is represented in a

diagram upon the principle of delineation, which was first employed by Mr. Ware, in his admirable treatise on this subject[7].

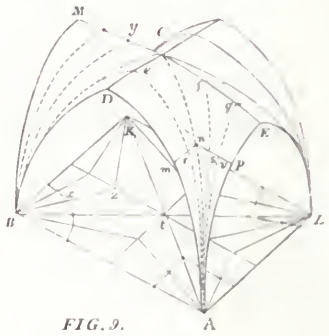


FIG. 9.

A B K L are the points whence the ribs spring, and between which is given the plan of the vault in a kind of diagonal perspective. A C, B C, K C, L C are the diagonal ribs or great cross springers (termed *croisée d'ogives* by De l'Orme). A *c* A *f* A *g* are the intermediate ribs of that spandrel of the vault which lies nearest to the eye in the diagram. These intermediate ribs are termed the *tiercerons* by De l'Orme, which being a very convenient word, I shall employ. Now in clerestory vaults, the transverse dimension of every compartment is commonly about double that of its longitudinal dimension. A D will, therefore, be the transverse rib of the vault, and A E the rib which lies next the wall of the clerestory or the *wall rib*, as I have ventured to call it, the *formeret* of De l'Orme.

In this figure I have shown one *tierceron* between the transverse and diagonal ribs, and two between the wall rib and diagonal rib; but the number varies in different examples. The figure agrees with the vaults of the choir of Lichfield and the south transept of Hereford.

One tierceron in each space D C A and C A E is to be found in Lichfield nave and Lady Chapel, Norwich cloister, Exeter side aisles, Lincoln nave, Westminster nave and cloisters, and in the vault at the intersection of the nave and transept at Amiens cathedral. Sometimes three and one are employed, as in Exeter nave, or three and two, as in Norwich nave. Much of the effect and character of these vaults depends upon the curvature of these tiercerons, and also upon that of the diagonal and transverse ribs between which they are placed; and even in the simpler vaults, which have only the diagonal and transverse ribs, this curvature governs the character of the vault by determining the form of the spandrel solid.

It is evident, indeed, that if a given parallelogram is to be vaulted with a groined and ribbed vault, and the crowns of the arches are all to be nearly at the same height, that some geometrical difficulties will be introduced in the management of the forms of arches of such different spans as the transverse, longitudinal, and diagonal ribs, and this difficulty was much greater before the pointed arch was introduced.

[7] Tracts on Vaults and Bridges.

The vault of the castle at Newcastle, already cited and explained, is a parallelogram of twenty-seven feet by twenty, and the three spans are here accommodated by employing semicircular arches and stilting them at their imposts to bring their crowns to the same level. This, as I have shown elsewhere[8], was the Roman expedient, and was employed in the baths of Diocletian and Caracalla, of course without the diagonal rib. The side aisles of the chapel in the White Tower of London, however, have plain groined vaults without ribs upon a parallelogram, exactly upon the same principle as that of Diocletian's baths, and with the waving groin, which I have, in the passage just referred to, shown to be a necessary result of such an arrangement.

The side aisles of the nave of Peterborough cathedral are examples of the same difficulty, which is overcome without the use of pointed arches by the new expedient of employing a *segment* less than a semicircle for the diagonal rib, or, in other words, by placing the centre of the circle below instead of above the level of the impost or springing. The parallelogram to be vaulted in this case is about fifteen feet by eighteen feet, but from the massive construction of the piers the bounding ribs are contracted in their spans, especially that on the long side which is next to the nave. The spans of the transverse and longitudinal ribs of the vault are twelve and fifteen feet, and of the diagonal rib twenty-one, and their crowns are nearly at the same level. To meet this difference of proportion between the spans and height, the longitudinal rib is slightly stilted, and the transverse rib very much so; but the diagonal rib is a small segment of a circle, and therefore springs off the abacus at a considerable angle, and in a manner totally at variance with the two neighbouring ribs, which rise from their imposts with a slight inclination backwards, forming horse-shoe arches.

After pointed arches were introduced, the difficulty of adjusting these three arches was greatly diminished; but notwithstanding the possibility of making pointed arches of any proportion of height and span with their centres of curvature upon the impost line, it will be found that the old expedient of placing the centres of curvature above or below the impost line, for the better adjustment of these arches, was still retained in pointed architecture until the four-centred arch was brought in. I shall proceed to examine this more at length, since it involves so much of the characteristic appearance of these vaults.

The ribs in early specimens consist each of an arc of a single circle, but

[8] Architecture of the Middle Ages, p. 72.

in later examples of two arcs of different radii conjoined so as to form the half of what are termed four-centred arches, since the term *rib* is applied to half the arch. Some ribs are, even in complex vaults, formed of three arcs, as I shall presently show.

In the first place, however, I will speak of ribs of a single arc only.

Ribbed vaults may have horizontal ridges, or they may be domical; that is, the point E of the ridge (*fig.* 9) may be at the same level or may be lower than C, and it may be also curved from C to E, in which case, as far as I know, it is always either straight or concave on its lower side, but not convex[9]. Sometimes, to suit particular cases, as, for example, to admit of a high window, the apex E of the wall rib is thrown higher than C.

Domical vaults are much more common on the continent than in England, and especially run into excess in the middle age vaults of Italy; however, we have some specimens of them, as, for example, in the nave of Worcester.

The form of the ridge is, however, one of the first things that should be observed in examining an existing vault, and is also one of the first things that must be settled in a proposed vault; for the form of the ridge decides the relative altitudes of the summits or crowns of the ribs.

Now supposing a rib to consist of a single arc of a circle, we may either place the centre of this arc upon the impost level, or we may allow it to be placed above or below that line. But the plan of the vault gives the span of each rib; also, when the height of the vault and the form of the ridges are determined, the altitude of the crown of each rib is also given. If, therefore, the centres are to be upon the impost line, the radius of each rib is given by these conditions; but if the centre may be above or below, we may for each rib take any radius we please.

For let A B (*fig.* 9.*a*) be the span of a rib which is given by the plan, and B C the height of its crown, which is also given, as already explained. Then since the rib is an arc of a circle, which must pass through the two points A and C, its centre must be on the line E D, which is a perpendicular upon the middle point of the chord A C. If, therefore, the centre of the arc is to be on the impost line A B, it can only be at D, where the two lines E D A B intersect; but if we are allowed to place it above or below this impost line, it may be at any points *d* or *e* upon the line E D.

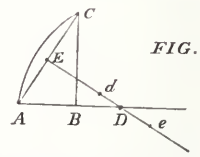


FIG. 9.a.

One set of workmen appear to have confined themselves to the first prac-

[9] The ridges of fan vaults are convex downwards, but they belong to the class of vaults with four-centered ribs.

tice, and another set to have allowed themselves the second; and it would be a very desirable thing to ascertain the exact curvatures of the ribs of a great many of these vaults, at the same time noting also their general character and appearance, with a view to determine the practice of the different schools, as well as to study the results with a view to improve modern practice, which is perhaps more deficient in this matter of curvature than in any other.

In the above proposition I have supposed that the form of the ridge was settled, or at least the altitudes of the crowns of the ribs, before the radii were determined, but we may suppose various other methods of proceeding; for example, that the pointed arches of the ribs should all be similar, that is, that they should all have the same ratio between their span and altitude. This rule produces a highly domical vault, because the crown of the diagonal rib is necessarily thrown very high above that of the other two. The Italian mediæval vaults appear to be governed by this rule as nearly as the eye can detect. But in England the ridges of the vaults are most commonly level.

In some specimens, however, other principles govern the relation of the curvatures; for example, in plate 77, Pugin's Specimens, is a diagram to show the curvature of a vault on the east side of the cloisters at Westminster. In this vault the ribs are each a single arc of a circle, with the centre upon the impost line, and *the diagonal rib has the same radius as the transverse ribs*[10], so that the vault is highly domical in its structure; it has no ridge ribs, but the ridge necessarily rises to the centre of the vault, since the crown of the diagonal rib is by this construction thrown so much higher than that of the transverse ribs. This principle of employing a common radius for the diagonal and transverse ribs agrees with many other examples, as I shall presently show.

On the other hand, there is also in Pugin's Specimens (vol. ii. p. 29) an excellent detailed drawing of the vault of the Lady Chapel, Southwark, in which the *ridges are horizontal.* The compartment is twenty feet six inches square, and the spans of the bounding arches are fourteen feet six, and of the diagonal arch twenty feet eight inches. The ribs or semi-arches are each formed of a single arc of a circle struck from a point eight inches below the impost level, and with a radius of nine feet five inches. The entire diagonal arch is struck from a single centre two feet seven inches below the impost level with a radius of

[10] The arches in this example are very highly pointed; the compartment is sixteen feet by eighteen feet two inches, and the height of the crown of the vault seventeen feet seven inches, or about eighteen feet if measured to the vaulting surface. The height is, therefore, the same as that of the long side of the parallelogram, which perhaps was the principle that in this case determined the proportions.

eleven feet three inches, and is therefore a segment of a circle instead of being a pointed arch.

In many examples I have seen that the transverse rib is struck from centres *above* the impost level, and therefore its arch is a horseshoe, and in the same vault the diagonal rib will often have its centres *below* the impost level. On the contrary, in the north transept of Hereford cathedral the centres of all the vault ribs are very considerably below the impost level[11]. I have shown that when the centres are allowed to be placed out of the impost level, there is a choice of many radii for the curve of a rib of given span and altitude, and of course as the radius increases, the rib approaches nearer to a straight line. But the effect upon the general form of the spandrel solid FDEA, *fig.* 3, or DCEA, *fig.* 9, is the principal point to be attended to, and this is best appreciated by considering the form which its middle plan assumes, that is, the form of a horizontal section taken at about half way up the arches, as at KQ, *fig.* 3, or perhaps a little higher, as at *mnp*, *fig.* 9. If the ridge ribs are level, as in this figure, the plan at the crown of the vault DCE will necessarily be a rectangle, but by different arrangements of the curvature of the ribs we may make the middle plan *mnp* assume any figure we please.

Thus in the simple vault with transverse and diagonal ribs only, as in *fig.* 3, we may, by making AB more or less curved, cause it either to lie between AD and AE in such a manner that a horizontal rod which touches these two ribs half-way up, will also touch AB; or we may make the middle point of AB lie in front of such a rod, the effect of which is to make the spandrel solid appear convex in front, and approach to the form of a fan-vault, which is the case in Pugin's second example above quoted; or else we may make the middle point of AB lie in the opposite direction, so as to make the solid concave in front: of each of which dispositions examples may be found. Similarly, when intermediate ribs are added, as in *fig.* 9, they may be disposed in various ways so as to affect in a similar manner the form of the middle plan, and throw it into various figures. By going to the upper surface of a vault, and looking down into the *pockets* or cavities which lie over the shafts, and which are in fact the insides of the spandrel solids, the middle plan will be

[11] These arches of Hereford north transept are so excessively straight-sided, that I measured them carefully, and with the following results. The height BC (*fig.* 9. *a*) is seven feet eight inches; the span is eleven feet six inches (so that the height is two-thirds of the span). The versed sine, or distance of the middle point E of the chord AC from the arch, is seven inches and five-eighths. The radius obtained from these measures, either by calculation or by laying down the arch to scale, comes out eighteen feet five inches, and it also appears that the vertical distance of the centre of the segment AC below the impost line is very nearly equal to the altitude BC of the crown of the arch above that line.

more distinctly seen than from below, and in making architectural notes its general form at least should always be recorded.

Since this middle plan affects the character and appearance of the vault so materially, I will show how, by a very simple construction, it may be employed in giving any desired form to the spandrel solid; and although I do not mean to say that it was so employed by the middle age architects, it may be made useful in examining and comparing their works.

Let *fig.* 9 (page 13) be a vault of which the plan is given, and of which the height of the apices of each rib, E, *g*, *f*, C, *e*, D, are also determined, as well as the middle plan *p*, *v*, *s*, *n*, *r*, *m*. The ribs being each a single arc of a circle, it is required to find the radius and centre of each rib. Now we have given for each rib three points through which it must pass: namely, the springing at A, the middle point, and the apex; therefore the question reduces itself to the common workman's problem, Given three points to describe an arc of a circle through them[12]. The complete construction for a vault with tiercerons is shown in *fig.* 10.

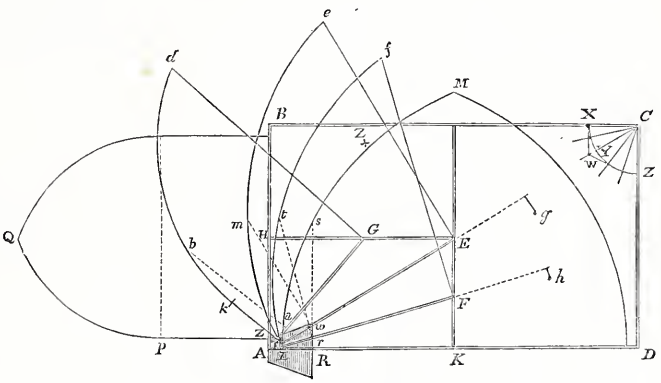


FIG. 10.

Let ABCD be the plan of the vault, AE the diagonal rib, AF AG the tiercerons, AH the clerestory rib. Draw LM of the required figure for the transverse rib LK, and also ZPQ the figure of the clerestory rib, which (as is shown at page 7) will be raised upon stilts, as at AP. Find the point *s* at half the height KM of the transverse rib, and draw R*s* perpendicular to A*k*. Draw the middle plan R*w*Z

[12] According to Philibert de l'Orme, the simple geometrical construction by which an arc of a circle is described through three given points (not in one straight line), is strangely termed "Manière de trouver les trois poinctz perdus." The curved templet or wooden sweep which is obtained from this process is called the "*cherche ralongée*."—"Inventions pour bien bastir," p. 21.

The fact of this problem having a familiar name shows it to have been in common use amongst workmen. Our workmen similarly term the mode of setting out a rectangle (from Euc. i. 47) the *rule of six, eight, and ten*, these being the convenient whole numbers of feet that possess the required property, namely, that the sum of the squares of the two first shall equal the square of the last, or 36+64=100. This rule is given in Vitruvius (b. ix. c. 2) from Pythagoras, and the numbers of feet used are three, four, and five.

of the spandrel according to the required form, also L Z the plan of the ribs upon the abacus.

To find, then, the curvature of any rib, as for example of the tierceron A F. If the ridge rib E K be horizontal, the height of the point F will equal that of the point K. Set off F*f* perpendicular to A F and equal to K M; and because *r* is the seat of the perpendicular from the point where the tierceron passes through the middle plan, set up *r t* perpendicular to A F and equal to R *s*. Then will L, *t* and *f* be three points through which the required rib passes, and the centre *h* found by the common rule, will be the centre of curvature of the rib. In the same manner will be obtained the centre *g* of the diagonal rib L *m e*. The arrangement of the rib upon A G is more difficult, for as it lies between two ribs, A H and A E, one of which is stilted above the other by a distance Z P, it is necessary to stilt also the rib upon A G by about half that distance. Set up, therefore, a perpendicular T *k* equal to about half Z P, and obtain the other two points *b* and *d* as before. *z* will be the centre of curvature of *k b d*.

Any other forms may be given to the middle plan, as shown at the angle c of the same figure by X Y Z, or at X W Z, or at B and L in *fig.* 9. I have drawn the diagram *fig.* 10 upon the hypothesis that the middle plan shall be taken exactly at half the vertical height of the arch, and that the ridges shall be level. If, however, the ridges be curved into any given figure, that curvature will give the separate altitudes of the crowns of each rib, and therefore, instead of setting up *k* M F*f* E *e* G *d* all equal, they must be made respectively equal to the altitudes thus obtained from the given ridges.

Also it may be better to take the middle plan higher up, because the form of the spandrel will be developed more clearly; for example, let it be taken at a point midway between the springing and the crown of the arch measured upon the arch itself. The point *s* being assumed half way between L and M, the remainder of the process will be the same, but the middle plan R *w z* will come out larger in proportion to the rest of the figure. Again, I have drawn the transverse rib first, but it may be better to begin by drawing the diagonal rib A *e* first, as that, from its greater span, is the most difficult to manage; in which case the point *m* must be assumed at the proper height for the middle plan, which will then be derived from the perpendicular *m w* instead of from the point *s* and perpendicular *s* R. I have reason to believe that the diagonal rib was often the first rib settled by the mediæval architects, as it so often appears in the form of a segmental or semicircular arch. The want of its point is concealed by the boss.

A common method of executing modern Gothic vaulting, especially in plaster, has been to obtain the form of the diagonal ribs, as A C, *fig.* 9, by ordinates from those of the transverse ribs A D, A E. The effect of this is, that the entire vault appears as if it consisted of two waggon vaults, crossing at right angles, and a horizontal rod moved from top to bottom in contact with any pair of opposite arches B M A E will touch the diagonal ribs B C A C and the connecting vaulting surfaces throughout. This is the genuine principle of the Roman and Italian groined vault, but is altogether foreign to the principles of Gothic architecture, in which every rib should spring as a separate and independent arch, and in which the elliptic curves produced by this method are totally at variance with the characteristic forms of the style.

De l'Orme first taught this method of projecting diagonal groins by ordinates, and applied it to the wooden cradling of an Italian vault in his Nouvelles Inventions pour bien bastir (1578, p. 20). This form of vault, however, is a kind of square dome *(cul de four quarrée)*, but requires the same diagonal curves for its groins (or rather *ridges*) as the Roman cross vault. The latter vault is not amongst the examples of stone-cutting in De l'Orme's book. The square dome is also given by Maturin Jousse with the same method of ordinates *(Le Secret d'Architecture,* 1642, p. 127), who also gives, for the first time, the Roman groined vault *(Voûte d'Areste quarrée,* p. 157) under different shapes and plans, which becomes a standard example in all the succeeding writers upon the subject, as Derand, De la Rue, Frezier, &c. But this method was never intended by them to be applied to Gothic rib vaulting. The Gothic style had grown out of use when De l'Orme wrote; but as a matter of curiosity he has described the curves of a Gothic vault (in ch. viii.), in which every rib is perfectly independent of the other in its curvature. Each rib consists of a single arc of a circle whose centre is *upon the impost level*, and they cannot be therefore connected by projections. They all form pointed arches of different proportions, with the exception of the diagonal arch, which is very nearly a semicircle. The vault in question consists of diagonal ribs, with one intermediate tierceron in each angle, as in *fig.* 10, but that the plan is a complete square. The ridge-rib or *lierne* E K is not horizontal, but slightly curved, so that the height of K above the impost plane is to that of E as about nine to eleven. The curve of the diagonal rib was first drawn (as De l'Orme himself says), then apparently the relative altitudes of the points E and F (that is, the lines E *e* F *f*), were determined, by drawing the proposed curve of the *lierne;* and as the centres of the arcs are upon the level of the imposts A E A F, nothing remained but to draw the arcs of circles each through the two

points *t e l f*. For, as I have already remarked, only two points are required to determine the circles when coupled with the condition that the centre shall be on the line of the impost.

This may have been the genuine French Gothic method, but in our English examples the centres are commonly placed without respect to the impost level, and the general forms of the vault are different from those which are produced in this manner, as already mentioned. It is easy to see, however, that this method of De l'Orme is very far removed from the projection system, and that from its simplicity it was in all probability one of the rules of the olden time.

Derand has also a chapter upon the Gothic vaults, but it appears to have been a mere comment upon De l'Orme, and indeed he wrote too late (1643) to be able to collect any genuine traditions of the Gothic methods; whereas De l'Orme himself lived so close to the Gothic period[13] that he might well in his youth have been taught by Gothic masons. Derand, however, says, that in this style the ribs are always made arcs of circles, elliptical or other curves being inadmissible, although he can see no reason why they should not be used, but that their effect upon the eye is not so agreeable (p. 177). He then proceeds to give the method of describing the arcs, which is manifestly a mere amplification of what De l'Orme had said.

De la Rue is silent upon the subject, but Frezier, 1738, has given the same matter as Derand, amplified, and with many very sensible remarks appended thereto[14].

It is not, therefore, from the French writers that the absurd application of De l'Orme's projection method to Gothic ribs is due; I believe this honour must be awarded to the ingenious Mr. William Halfpenny[15], who, living at a period when Gothic architecture had sunk into complete neglect, may very well be excused for having misapplied as he has done the projection system to the finding the "Mitre Arch of a Regular Groin when the Intersecting Arches are Gothick ones" (p. 16). In this he has been followed by Mr. Nicholson[16], who has also taken much trouble to construct a Gothic vault with *cuniconoidal surfaces* and upon other fanciful hypotheses, which, as they produce curves for the ribs totally different from the genuine ones, can answer no purpose but that of destroying the mediæval character of the work[17].

[13] He flourished from 1536 to 1577. The contract for King's College vault is dated 1513, and the first stone of St. Peter's at Rome was laid in 1506.

[14] Traité de Stereotomie, t. iii. p. 23, 3rd edit. 1769.

[15] Art of Sound Building, 1725.

[16] Builder's Director, new edit. 1834, p. 79.

[17] Treatise on Masonry and Stonecutting, 1828, p. 91.

The south walk of the cloisters of Westminster has a vault, the ribs of which approach more closely in their appearance to projected ribs of this kind than any I have seen elsewhere, and I therefore took some pains to examine them, and found that they certainly were not so projected, but that the effect is due to the form of the middle plan, which is very nearly a square. Nevertheless the aspect of this vault is exceedingly flat and vapid compared with the bolder arrangements of the vaults in the other walks of the cloister.

In *figs.* 10 and 13 I have placed the elevation of each curve upon the plan of its own rib. This neat arrangement is employed by De l'Orme in many of his diagrams, and has been followed by all writers up to the present time. Of course, by adopting it, I do not mean to assert that it was followed by the Middle Age workmen, but rather I have employed it as a compendious and universally understood formula for setting out. The methods given in these figures would be the same if the curves were drawn separately by the side of the plan, which De l'Orme has actually done in his Gothic diagram, after the manner of *fig.* 11 or 16.

It may be observed also that he has taken the pains also to draw moulds for the stones of the vaulting surfaces or *pendentifs* as he terms them. This, according to his own confession, was very seldom done, these vaults being more usually formed of brick or of stones so small or at least so thin that the curvatures and angles of their beds might be neglected, which indeed is plainly the case in all the existing English examples that I have examined. It must be clearly understood that I do not suppose the method of *fig.* 10 to be a restoration of an ancient practice. My object is to show clearly the mutual geometrical dependence upon each other of these three things which belong to a vault upon a given plan with single-arc ribs, namely, the form of the ridges, the middle plan of the spandrel, and the curvature of the ribs. Of these, if any two be determined, the other follows as a matter of course. It seems, therefore, most natural for us to select the two for determination which are the most easily appreciable by the eye, and these are the ridges and the middle plan. The method which I have given proceeds in this manner, and furnishes a general process by which we may imitate the various arrangements of these two things in the specimens of different ages.

In the old time, one style alone was practised in each period, and a few simple rules were sufficient for the purpose. The change or improvement of one or more of these rules introduces new features and new characters, but which still are alone employed as long as they last, and until they are in turn superseded. But we, imitators of all styles, must have more comprehensive

and flexible rules, capable of imparting to our works the characters of every age in turn. This necessarily gives to the methods which we invent and employ a much greater degree of complication than is likely to have belonged to the rude practical geometry of the Middle Age workmen; each of our constructions being in fact a general formula, which includes many particular instances, every one applicable to a separate period.

Notwithstanding, therefore, that I have employed the middle plan in determining the curvatures, I think it most likely that the different forms of the middle plans which may now be observed resulted from different rules for finding the centres and radii of the ribs, which were employed by the different schools of workmen according to their age or nation. In fact, in some examples the geometrical difficulties are very clumsily botched over, while in others the ribs are so beautifully adjusted in their relations that the greatest possible boldness and grandeur of effect is brought out, and to a degree which never appears after the four-centred arches are introduced.

When the centres of single-arc ribs are placed upon the impost level, we have no longer the liberty of disposing at pleasure both of the form of the ridge and of the middle plan of the spandrel. One of these being settled, the other follows as a matter of course. It would lead me too far into geometrical investigations for the nature of the present paper were I to follow out these principles to their consequences. This I must leave for a future opportunity. But in this section my purpose is rather to direct investigation towards certain points and characteristic features in the adjustment of the ribs, which appear to me to exercise a great influence over the form of the vault, and even over its æsthetic character, and to the neglect of which may be attributed much of the feebleness of appearance in modern Gothic vaulting.

In vaults of the Roman and Italian styles, of which the groins are without ribs, the vaulting surface is the leading feature, and the disposition of it the only object to be attended to. But in Gothic ribbed vaults, on the contrary, the ribs are the principal features, and the surface of the vaults subordinate. To maintain this subordination of the vaulting surface to the ribs, the latter should branch off from the abacus with the greatest possible appearance of mutual independence as separate arches, an appearance which is better given by single-arc ribs than by double-arc ribs or semi-fourcentred arches. Also the vaulting surfaces or pannels of contiguous compartments should by no means have the appearance of continuity, which is given by the projection system, but which immediately suggests the idea that the surfaces really constitute the mechanical vault independently of the ribs, which seem to have

been subsequently added, and might be removed without destroying the vault; instead of which the ribs really support the vault, and should appear to do so in the decorative as well as in the mechanical construction.

The apparent mutual independence of the ribs is increased in the best specimens by the manner in which they start from the abacus, some being more prominent than others. This is easily managed in the diagram *fig.* 10, by placing the feet of the curves at different distances from the centre A of the abacus.

I have shown (to return from this digression) that a very simple geometrical process enables us to obtain the curvature and form of every rib from the two plans and the heights of the ribs combined, but that without some such process they could not have been arranged with so manifest a power over the effect of the combination as the existing examples make evident.

In vaults, however, whose ribs consist each of a single arc of the circle, every rib of the group will spring off from the common abacus at a different angle, if the centres of their respective circles be some above and some below the level of that abacus. In the first case the ribs will be slightly horseshoed or stilted, and in the second will start abruptly forward. These discrepancies may be seen in the majority of these vaults, and it was perhaps to remedy them that four-centred arches were introduced for the ribs, so that each rib should consist of two arcs of circles combined so as to have a common tangent at their junction. For when ribs are thus formed of two arcs, any number of them may start from the abacus at the same angle and even with the same curvature, and yet may have each a different height or span under certain simple limitations.

Now a four-centred arch, or, which is the same thing, a two-centred rib, may have its upper radius adjusted to accommodate different spans and heights in two ways, when its lower radius remains constant.

First, *fig.* 11, let ADCB be the quarter plan of a vault, and, for simplicity, suppose the ridge rib DB level, so that all the ribs will have the same height at the apex. Transferring the lengths of the ribs upon the plan to A*e* and A*b*, set up D*h eg bf* equal to each other and to the height of the ribs, and let the arc AE, whose centre is *e*, be the given lower circle of the ribs, which is to be the same in all. Produce E*e* to H, then any circle struck through E whose centre is upon this line will touch the circle AE at E, and thus answer the purpose of the upper circle of the rib. By taking

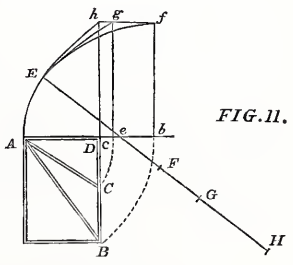


FIG. 11.

different radii for this upper circle, therefore, we can make the ribs pass through the points *h g f*, as shown in the diagram, where H, G and F are the respective centres of the ribs E*h* E*g* E*f*.

[18] In this example the ribs not only start all with the same curvature, but the change of curvature is made at the same height E in all, consequently the upper circles have all a different radius.

Secondly, let it be required that the upper circles shall all have the same radius as well as the lower circles. In *fig.* 12, A D D*h* is the span and height of one rib, A B B*f* those of another rib. C is the centre of the lower circle A*b*, which is common to both ribs. But as the upper circles are to be also the same, the curvature cannot change at the same height in both. *b* H being the given radius, the centre of one upper curve *b h* is at H, and of the other *c f* at F. It is easy to see that these centres will lie in the circumference of a circle whose centre C coincides with that of the lower circles and whose radius C H is the difference between the radii of the lower and upper circle of the ribs; also a centre can be found at once, so that its arc shall pass through any given point, as *f*, by intersecting the locus H F with an arc whose centre is *f* and radius that of the upper circles.

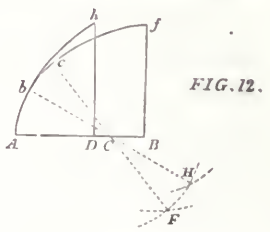


FIG. 12.

Which of these principles of adjustment were employed by the Middle Age architects I do not know, but it would be very desirable to measure accurately a good number of examples, to ascertain whether the curvature of the upper circles is often the same in all the ribs as well as the lower.

There are two working drawings of vaults, with intermediate four-centred ribs, in Pugin's Examples, upon which the curvatures of the ribs are indicated, apparently with great accuracy. In one of them, the gateway of Magdalen College, the ridge ribs are horizontal, and consequently the arched ribs all of the same height. Each rib consists of two arcs of circles, but the lower circle is of very small diameter with respect to the upper circle, its radius being about one-ninth of the latter, and the same in all the ribs. All the upper circles of these ribs appear in this drawing to have the same radius, which is equal to the span of the transverse arch.

The other example is the groining of a bay window of Eltham Palace, also having one intermediate rib between each diagonal and wall rib. The ridge

[18] The centres are easily found in each case, as for E*f* by joining E*f*, bisecting and drawing a perpendicular, which will intersect the line E H in the required centre F.

ribs are not horizontal, consequently in describing the curves of the arched ribs, the ridge ribs were probably first determined to give the heights of these ribs. Each rib, being half a four-centred arch, consists of two arcs of circles, the radius of the lower arc being a little less than half that of the upper arc, and this latter radius is again equal to the span of the smallest arch. These may be accidental proportions; however, the two radii are respectively the same in every rib, and consequently the different heights and spans are accommodated, as in *fig.* 12, by employing different proportional lengths of the two circles in each rib. The centre of the lower circle is in all placed on the impost level, and this I believe to be universal in four-centred arches.

The wall rib, in examples of this class, is often different both in its lower circle and upper circle from the other ribs, and in some cases the accommodation of heights is but clumsily effected. In the vault of Queen's College gateway at Cambridge, *fig.* 16, the ridge ribs are horizontal. The elevations of the principal ribs are shown upon G A, where G *m* is the curve of the wall rib G F, G *n* that of the transverse rib G A, and G *q p* that of the diagonal rib G K. The wall rib has a lower circle whose centre is *t*, and radius *t k* greater than those of the other ribs, and its upper circle *k m* is different, so that this rib is quite different from the others. The diagonal rib, transverse rib G A, and tiercerons have all the same lower circle G *y* with radius *s y*, and the same upper circle *y n*, so that the curvatures of these ribs are identical up to *q*, but the different spans are accommodated by breaking the curve off abruptly, as from *q* to *p*. As this change of direction takes place near the bosses B, C, D, it is scarcely perceptible unless closely looked after.

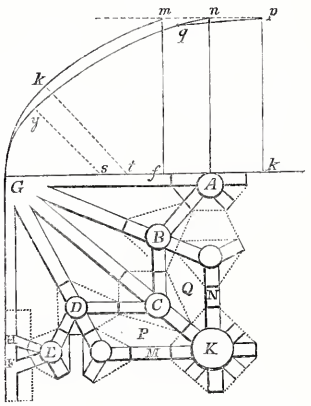


FIG. 16.

The vaults of the side chapels of King's College, Cambridge, are excellent specimens; those towards the west end, namely, four on the north side and three on the south side, have four fan-vaults similar to that of the chapel itself, and the two extreme north-eastern chapels have very elegant vaults of an earlier date than the great vault. The remainder of these small chapels are vaulted with plain vaults, which are included in the same contract with the fan vaults, and are specified as to be made of "a more coarse werke" (vide contract in Britton's Ant. vol. i.) These chapels are parallelograms of twenty feet six inches by twelve feet. The plain vaults have intermediate ribs or tiercerons, precisely in plan the same as *fig.* 9. The ribs are, however, two-

centred and all of the same curvature, and the ridge ribs consequently have the figure of *fig.* 20. The vault is built of rib and pannel work. The vaults of the two north-eastern chapels are of the class which I have in a succeeding part of this paper denominated *lierne vaults*, and have an elegant pattern of the stellar kind, which is so contrived as to form not only stars round the angles, but also a six-rayed star round the centre. It has in all twenty-three bosses. This vault is also built of rib and pannel work, and the boss stones are formed on the principle of *fig.* 16, each stone including a portion of pannel between the stump of the ribs. The curvatures are beautifully managed. The ridges are both horizontal, and the ribs all leave the impost with the same curvature, and apparently their upper or crown curves have all the same radius, the different spans being accommodated on the principle of *fig.* 12. The transverse arch is very nearly equal in height to its own span. On the whole, these vaults are excellent specimens, but are seldom seen, as the chapels are shut up and neglected, and used as a workshop or lumber place.

I am indebted to the kindness of Charles Barry, Esq. for the exact measures and curvatures of the vault of the crypt of St. Stephen's Chapel, at Westminster, which follow. The details and arrangements of this crypt have been published in various well-known works, and therefore the diagram plan of one quarter of a bay, in *fig.* A, will be sufficient for our present purpose, which is merely to give the curvatures of the ribs.

A is the central boss of the vault.
B C D E, the other bosses.
F, one of the piers.

The respective diameters of the bosses are as follows:—

Boss A, 3 feet 3 inches diameter.
B, 1 5
C, 1 3
D, 1 7
E, 10

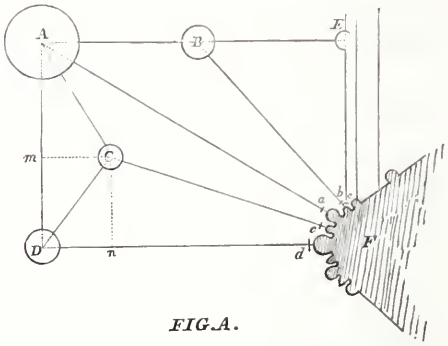


FIG. A.

The position of C on the plan is given by the perpendiculars C *m* C *n*, from the centre of the boss upon the lines A D D *d* respectively, of which C *m* = 3 ft. 6½ in. and C *n* = 3 ft. 11 in. The ribs A D A B and B E are all straight, but D C and A C are slightly curved; the first having a rise of 1 in. and the second of ⅞ in. The curvature of the ribs A *a* B *b* C *c* D *d* E *e* are shown in the following table, the explanation of which will be found on the succeeding page.

Curvatures of the Ribs in the Crypt of St. Stephen's Chapel, in feet and inches.

Vertical ordinates.	Horizontal distances.	Rib A a	Rib D d	Rib C c	Rib B b	Rib E e
B b	A B	1 8 10 $8\frac{1}{2}$	$7\frac{1}{2}$ 10 $5\frac{1}{2}$	8 10 $4\frac{5}{8}$	 11 $1\frac{7}{8}$	3 11 1
C c	B C	1 $1\frac{7}{8}$ 10 $7\frac{1}{8}$	1 10 3	1 $6\frac{1}{8}$ 9 $9\frac{7}{8}$	1 $5\frac{1}{2}$ 10 6	1 10 $6\frac{1}{8}$
D d	C D	1 10 $4\frac{3}{4}$	1 9 $11\frac{1}{4}$	11 9 $3\frac{7}{8}$	1 9 $11\frac{1}{4}$	1 9 $11\frac{3}{4}$
E e	D E	1 10 $1\frac{5}{8}$	1 9 $6\frac{1}{4}$	1 1 8 $7\frac{7}{8}$	1 9 3	1 9 $1\frac{5}{8}$
F f	E F	1 9 $9\frac{3}{4}$	1 9 $0\frac{5}{8}$	1 7 $11\frac{1}{8}$	1 8 $5\frac{3}{8}$	1 8 $1\frac{3}{4}$
G g	F G	1 9 $4\frac{1}{4}$	1 8 6	1 7 $0\frac{3}{8}$	1 7 $6\frac{1}{4}$	1 6 11
H h	G H	1 8 $10\frac{1}{2}$	1 7 $9\frac{1}{2}$	1 6 $0\frac{3}{8}$	1 6 $3\frac{1}{2}$	1 5 1
I i	H I	1 8 $3\frac{5}{8}$	11 7 $1\frac{1}{8}$	1 4 $7\frac{5}{8}$	1 4 10	6 3 $8\frac{3}{4}$
K k	I K	1 7 $7\frac{7}{8}$	1 1 6 $1\frac{1}{8}$	1 2 $8\frac{1}{8}$	1 2 $8\frac{1}{4}$	6 0
L l	K L	1 6 $9\frac{1}{8}$	1 4 $10\frac{1}{2}$	$9\frac{7}{8}$ 0	8 0	
M m	L M	1 5 $8\frac{3}{4}$	1 3 5			
N n	M N	1 4 5	6 2 $4\frac{7}{8}$			
O o	N O	1 2 $10\frac{1}{2}$	$3\frac{1}{2}$ 1 $7\frac{3}{8}$			
P p	O P	6 1 $8\frac{3}{4}$	5 0			
Q q	P Q	6 0				

These curvatures were measured by vertical ordinates which rise from a horizontal base at the level of the abacus or impost line of the pier F, and are for the most part taken at a distance of one foot apart, but in some places this equal spacing of the ordinates has been interfered with by local circumstances or obstructions.

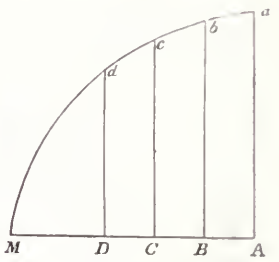


FIG. B.

The table is arranged in this manner: M *a*, *fig.* B, being one of the ribs, let M A be the horizontal line or base, and A *a* the central ordinate, therefore *a* will be the crown of the arch or rib. B *b* C *c* D *d*, &c. are the other ordinates in sufficient number. Then the feet of these ordinates are indicated by the capital letters in order, beginning with A for the central one; and the upper extremity of each ordinate is indicated by the small letter which corresponds to the capital at its foot. In this way A *a*, B *b*, C *c*, &c. will indicate the height of the ordinates, and A B, B C, C D, &c. their respective horizontal distances. The ordinate at the springing, as M, will be necessarily equal to zero. By following this system, a great number of curvatures may be arranged and published without requiring engraved figures.

I have laid down these ordinates upon a large scale, with a view to determine the radii of the circles. However, it will always be found in this operation that the irregularity of the workmanship and the settlement of the work will occasion such deviations from the original form, as to leave the exact radius and centre of the arc a matter of some doubt. For this reason, the fairest and best plan is to publish the ordinates in every case, without attempting to form hypotheses; for it will only be by collecting a great number of such examples, and comparing them, that we can hope to deduce general rules. I will merely state the radii as far as I have been able to determine them.

The ribs A *a* D *d* (*fig.* A) are semi-fourcentered arches, but the ribs C *c* B *b* E *e* are each of them arcs of one circle. The ribs A *a* D *d* agree so nearly in form, that it is evident that their curvatures are intended to be the same as far as they go together, for A *a* is of course of a larger span. The centre of the upper curve of A *a* is immediately below its crown, so that in fact this diagonal rib is a semi-three-centred arch. This agrees with the example already quoted from Pugin of St. Saviour's vault, and is, I believe, a pretty general practice. The radius of this upper curve is 15 ft. 10 in., and its centre is 5 ft. below the impost level. The radius of the lower circle is 10 ft. 8 in., and the line which contains the two centres makes an angle of 38 deg. 20 min. with the base or

impost level. The radius of E *e* is 11 ft. 11 in. and its centre is 3½ in. above the impost line. The radius of B *b* is 14 ft. 9 in. and its centre is 2 ft. 7 in. below the impost line. The radius of C *c* is 13 ft. 6 in. and its centre is 2 ft. 6 in. below the impost line.

The height of the central ordinates, that is, of the crowns of the arches, cannot be measured, because the bosses cover them, consequently they are omitted in the table.

Section III.—On the Ridge Ribs, Liernes, and Bosses.

The intermediate ribs or tiercerons which have been considered in the last section are each of them semi-arches springing from the same abacus as the principal ribs, and, as far as their separate voussoirs are concerned, no new difficulty is introduced by them into stone-cutting.

But, in addition to them, we find other intermediate pieces or short ribs introduced in the vault, by which an enriched appearance is given to it; and which, instead of springing from an abacus, merely connect the other ribs at different points of their height. One set of these pieces, the *ridge ribs*, occupy the ridges of the vault, and therefore connect the crowns of the ribs alone. Another set, which I shall term the *Liernes*, connect the ribs at other points, or may connect the crown of one rib with some intermediate point between the crown and springing of another rib. For example, in *fig.* 16 (p. 27), the gateway of Queen's College, Cambridge, K M, K N, are ridge ribs, and A B, B C, C D, D E, E F, E H, are liernes.

Now as these pieces are not necessarily either straight or horizontal, their lengths and the angles of their beds cannot be obtained immediately from the plan, but necessarily require the use of a geometrical projection combined from the plans and elevations of the ribs.

The term *Lierne* is applied by De l'Orme to the short-ridge ribs which form a cross at the summit of the vault which he has given as an example, and which correspond to E D and D F in *fig.* 13 below; but I am inclined to think that the same word would have been used for the other short ribs, such as E M, M F, if they had occurred in his drawing. The word is a carpenter's word, and is also applied by De l'Orme, in his "Inventions pour bien bastir," to the short pieces which at different levels tie the wooden arches of his roof together, "les Liernes qui lient et tiennent en raison les dictz aiz pour faire les hemi-

cycles."[16] They are thus apparently *liens*, short ties (rather *struts*), or connecting pieces; and the word, whatever may have been its application, is a very convenient term for those ribs of a vault which do not spring from an impost, in opposition to those which do, and which are, as we have seen, termed transverse ribs A D *(fig.* 10*)*, wall ribs or *formerets* A B, diagonal ribs or *croisée d'ogives* A C, and *tiercerons* or intermediate ribs, or in general *branches* or *nervures*. So many of the terms that have been recovered of the Middle Age workmen in England are Norman French, that I see no objection to the employment of those French words which we cannot doubt to be genuine; I shall, therefore, venture to call these short ribs *liernes*, applying the term to every rib that does not spring from an abacus, excluding from it, however, the ridge ribs.

The intersections of the tiercerons with the ridge ribs and with the liernes are commonly covered by bosses. Every boss stone being thus a centre whence portions of ribs diverge at different angles and in different vertical planes, is in itself a complex figure, which likewise requires the employment of a geometrical system. It may be observed that the use of bosses is much

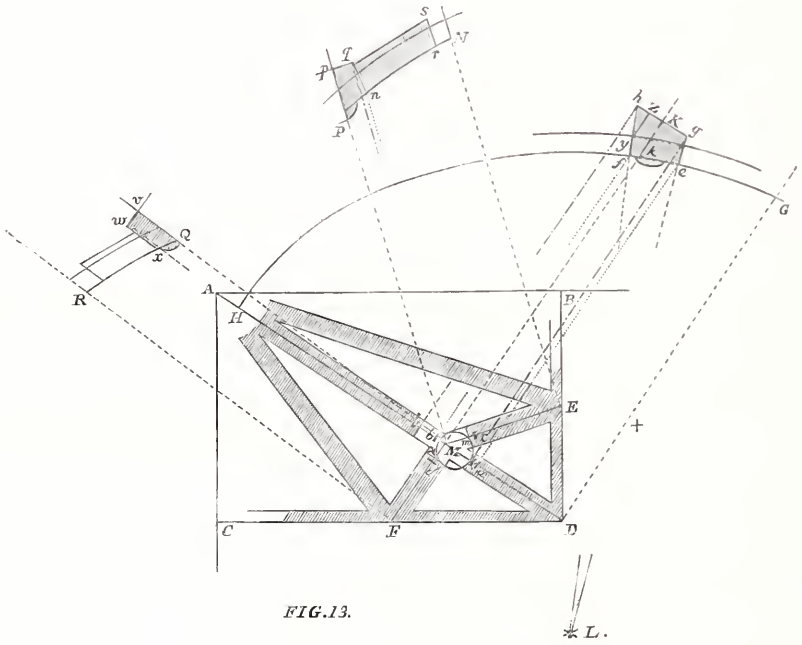


FIG.13.

older than the introduction of the liernes or even of the ridge ribs into the vaults; but as the geometrical process for obtaining the forms of all is very

[16] Page 13.

nearly the same, I will show what I conceive to have been this process, and then explain the evidence by which one part of it at least is proved to have been employed by the workmen of the period in question.

Let ABCD, *fig.* 13, be the plan of one quarter of a severy, of which the ribs spring from A. AD is the diagonal rib, and AE AF are intermediate ribs or tiercerons, springing also from A. EM FM are liernes, and it is required to obtain the shape of the boss stone at the intersection M, and also the forms of the two liernes FM EM, the curvatures of the ribs having been previously determined. Upon D set up DG perpendicular to AD and equal to the height of the centre of the vault; and upon AD describe HG, the elevation of the curve proposed for the diagonal rib. Since the middle planes[17] both of the ribs and of the liernes are vertical, their intersection will be a vertical line, the seat of which upon the plan will be M. Call this line *the axis of the boss*, and draw MK perpendicular to HD to represent this axis in the middle plane of the diagonal rib.

The carving which decorates a boss is commonly included in a circular or rather spherical form, but the centre of this circle is not always upon the axis of the boss; on the contrary, it is placed so as best to cover the meeting of the ribs. The circle described at M represents the space intended to be occupied by the carving. Mark points *a b c d* upon the rib and liernes to indicate the place of the joints on the *lower* surface of the boss stone, and project the points *a b* upwards to meet the curve of the rib at *e* and *f*. From the centre of curvature L of the rib, draw the joint lines *eg fh*, and draw *hg* perpendicular to the axis of the boss for the upper surface of the stone, which, as will presently appear, is always horizontal. This surface line must be drawn at a sufficient height above *k* to leave the proper extent of bed at the small end of the stone *eg*. Project the points *g, h*, downwards to meet the plan AD of the rib at *k* and *l*. Then will *k l* be the length of the upper surface of the stone in its proper relative position to the axis of the boss M.

This double projection, for example of the point *a* upwards to *e*, and of *g* downwards to *k*, is of constant use in this method, for the place of the joints is in every vault determined by the nature of the pattern which decorates its *lower* or visible surface, as we shall see more clearly in the complex fan vaults. But the shape of the stone is obtained from the plan or mould of its *upper* surface. To obtain this mould, therefore, we must begin by placing the joints upon the decorative surface, and then, by this system of upwards and down-

[17] By the middle plane is here meant a vertical plane seated upon the plan line of any rib (as AD), and which plainly divides such rib into two similar and opposite halves.

wards projection, we can obtain the intersection of the joints with the upper surface of the stone, and thence its upper plan, as we have begun to do in the example before us, where the joints *a* and *b* were first placed so as to leave a sufficient space for the carving of the boss, and then, by upwards and downwards projection, transferred to *k* and *l* to obtain their positions upon the upper surface.

The next operation is to obtain the section of the boss along the line ME, and the same operation will give the vertical section of the lierne ME. Draw MP EN perpendicular to ME. If the ridge rib DE be level, NE will be equal to DG; if not, the given form of the ridge rib DB will show the height of EN as already explained.

Also MP is the axis of the boss, and will therefore be equal to M*k*, and for the same reason P*p* will be equal to *k*K. The curvature of a lierne does not appear to have been in any case accurately determined. Sometimes they are made straight and sometimes a slight sweep is given to them as in the present figure, but which was evidently determined by eye merely.

For the joint *nq*, which connects the boss with the lierne, we must proceed by up and down projection as before, that is, place the point *c* upon the plan so as to clear the ornamental boss, project this upwards to *n* by a perpendicular upon ME. Draw the joint *nq*, and project *q* downwards upon the plan to *m*, which will be the seat of this joint upon the upper surface of the boss stone. The joint *nq* is not necessarily directed to the centre of curvature of the arc NP in a lierne, as it would be in a rib. *nqrs* is a section of an actual lierne from Canterbury, in which the joints *nq rs* at the two extremities are disposed at a small angle with each other, so as to prevent the stone from slipping down; but the joint *rs* is nearly vertical, and *nq* therefore very little inclined. In fact as the bosses at P and N are each firmly held up by their own ribs or arches AD AE, and the lierne acts merely as a strut or stay between them, there is no necessity to place the joints of the latter square to the curve, which in this and similar cases would either weaken the boss stone by cutting it back at *q*, or else make a larger stone necessary for it by carrying the point *n* nearer to N. The acute angle in the lierne at *n* renders the mouldings at that point liable to splinter at the joint, an effect that in truth may often be perceived in the practice of the age in question. I have already given a similar instance in *fig.* 5 (p. 12). However, the joints of the existing lierne vaults will show that they were placed in the manner here exhibited.

For the section M*d* of the boss, and for the lierne MF, proceed in precisely the same manner to describe the figure QR, in which Q*v*, equal to *k*K, is the axis of the boss, and *wx* the joint.

Thus we obtain the complete plan or mould *l m k t* of the horizontal upper surface of the boss stone, and may now proceed to cut it out of a given block as follows, having in the first place levelled its upper surface and transferred to it the plan *l m k t*.

The boss has four joints or beds, namely, at *l*, *k*, *m*, and *t*; and the vertical angles which these make with the upper surface are shown by the three sections of the boss which have been drawn, namely, those at *l* and *k* are *f h g* and *h g e*, that at *m* is *p q n*, and that at *t* is *v w x*. By the use of a bevel, therefore, these beds can all be worked, and upon each of them must then be traced by a templet the outline of the mouldings of the rib. The distance of its lower edge is shown for each bed by the same sections which have given the angle; thus *e g*, *f h*, *n q*, and *x w*, are in each case the distance of the lower edge of the templet from the upper surface of the stone.

This done, the form of the stone can be completed without difficulty.

The key to this method is merely the employment of the horizontal upper surface, which being parallel to the plan of the vault, the respective ribs make with each other upon it the same mutual angles which they do upon the plan itself; and the vertical angles of the beds are also, as we have shown, immediately referred to the same surface. This surface I shall venture to call the surface of *operation*, because its sole use is to simplify the operation of shaping the stone, in opposition to the beds or joints which are surfaces of *construction*, or to the lower face, which is a surface of *decoration*.

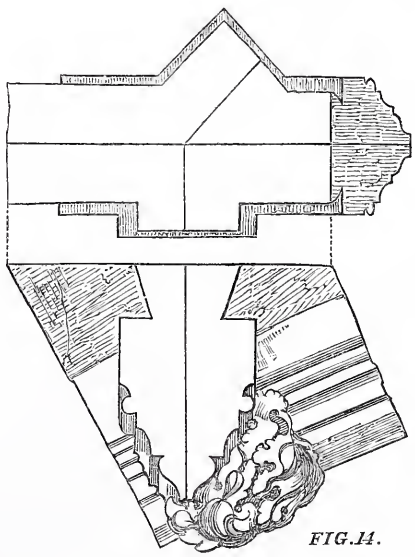


FIG. 14.

That this method is in principle the one which was really employed by our workmen can scarcely be doubted after the examination of existing examples. The boss stone which has resulted from the diagram *fig.* 13 coincides in all its angles with the form of one which is (or lately was) lying amongst many others in the nave of Canterbury Cathedral, the ruins of a capital vault which was taken down together with Lanfranc's Tower, and which has already furnished us with another example in *fig.* 7[18]. *Fig.* 14 represents the plan and elevation of this boss stone, in which is

[18] The plan of the vault from which this boss was taken was, however, much more complicated than that which I have given in *fig.* 13, but I have taken care to place the boss M in precisely the same

shown the horizontal surface of operation, still retaining the lines drawn from the axis of the boss in the direction of the respective ribs. Indeed, upon the upper surface of every vault which I have had the opportunity of examining when the boss stones are not hidden by rubble, I have always found that they had each the upper horizontal surface of operation, of the universal employment of which I have no doubt; for example, this is distinctly seen in the perspective view of the upper surface of the vault of St. George's Chapel at Windsor, *fig.* 32 (Plate IV.)

In explaining the above method, I have put it into a more compact and complete form than that under which it was probably employed. That the order of proceeding in the practical reasoning by which the form of the boss stone was elicited from the pattern of the vault, was virtually the same as that which I have given, can scarcely be doubted from the evidences that are still preserved to us by the horizontal surfaces of operation and the lines which they retain in the majority of existing examples.

In the following process I have retained the same general method, but have endeavoured to employ the least possible amount of descriptive geometry that is warranted by the remaining evidences. The actual process was perhaps intermediate between the two, or else the ruder method was used by one set of workmen and the more complete one by another set, which is the more likely to have been the case from the great difference of workmanship in the various examples that remain.

The simplest course of proceeding, then, that I can devise is this—draw the full sized plan of the ribs, liernes, and boss-circles, as in *fig.* 13; draw also the elevation of each rib, as NG, but not the elevation of the liernes. To work out any given boss stone, as M, mark upon the plan the place of the joints on the lower surface, at *a* and *b*, and project these upwards to *e* and *f*. Draw *e g*, *f h*, and the horizontal line *g h*. Level the block of stone to obtain the surface of operation, draw upon it the line which corresponds to the rib AD, and, having chosen a point upon this line for the axis of the boss M, draw lines from this respectively parallel to the liernes MF ME. From the axis point set off the distances K*h* K*g*, obtained from the section of the boss *e g h f* already drawn; and then, by means of the bevel, work the beds *h f g e*, the respective vertical angles of which to the surface of operation are given by the section.

Now with respect to the beds which receive the two liernes MF ME, I have

relative position to all its neighbouring ribs and liernes in this plan as in the original, which is all that is requisite for the purpose of showing the identity of the methods which I propose with those from which the form of the boss was obtained.

already stated that these beds are not wrought in a direction tending to the axis of curvature of the lierne, as is necessarily the case with the beds *hf ge* of a rib, which must be respectively directed to its axis L. The lierne beds, on the contrary, are wrought so as best to economize the boss stone. For these, then, it appears probable that no elevation of the lierne such as *r s n q* was made, although this would have been the most complete method. We may therefore proceed to work these beds at an angle which approaches, as near as the stone will allow, to the required direction, assuming the latter by guess, and only taking care that the lierne bed shall intersect the surface of operation in a line drawn perpendicular to the plan-line of the lierne already drawn upon that surface. When the whole of the boss stones as well as the plain voussoirs of the ribs are finished, the ribs may be erected, and each boss stone will be of course held up in its proper place by the rib to which it belongs, and of which it constitutes a voussoir.

It now remains to construct the liernes themselves, for which purpose a vertical or side mould may be easily made of thin wood, by *scribing* for each lierne between its respective pair of bosses, now fixed in their proper position in the vault. Lastly, the pannel stones must be shaped and fitted, and thus the vault completed.

The difference between this method and the previous one is, that it dispenses with the up and down projection and the resulting face mould of the surface of operation. Also the liernes are shaped by trial instead of their forms being obtained by descriptive geometry. But the appearance of these liernes in many existing vaults, the irregularity in the curvature, length, and angular position of corresponding pairs of these members, which ought to be exactly alike in these particulars, as well as the apparently arbitrary position of their joints, all seem to show that their forms were determined by a trial of this kind after the bosses were fixed.

The only geometrical preparation that is here assumed is the full sized plan of the vault and the elevations of the ribs, and without these it would have been impossible to shape the boss stone so that its upper surface of operation should be horizontal. In fact, the universal presence of this surface is a sufficient evidence of the employment of the elevations at least of the ribs, if not of the liernes.

The employment of a boss stone, that is, of a stone placed at the intersection of two groin arches, and provided with beds for the reception of the four ribs that thus meet upon it, is not coeval with the use of groin ribs, as might be at first imagined. In the early Norman examples, one pair of the diagonal

ribs was first erected as a complete arch, and the other pair of ribs set up separately, and made to abut against the first arch, meeting either a voussoir or a joint, as the case might be. A very curious instance of this kind may be seen at the east end of the Norman crypt at Gloucester. The compartments of the aisle which runs round the circular end are necessarily trapeziums in plan. The two diagonal groin arches are each a semicircle in a vertical plane, and they consequently intersect, not at their crowns, but at a point considerably lower down. That no geometrical method had then been invented to obtain the form of the boss stone at the intersection is evident, for one diagonal arch is complete in itself, and the other, as above, being built in two separate halves, abuts awkwardly and obliquely against the first, having been evidently left to shift for itself, just as the vaulting surfaces were in the same early period, as I have shown in the beginning of this paper. In the round church of St. Sepulchre, at Cambridge, the compartments of the aisles are also trapeziums upon the plan, but the awkwardness of making the semicircular groin ribs intersect below their crowns, is very ingeniously got rid of. Those points of the outer wall from whence every pair of neighbouring ribs spring, are placed at such a distance from each other that the four feet of the diagonal ribs in each compartment really stand upon a rectangle, and the ribs therefore intersect at the crowns in the usual manner.

In the eastern transepts of Canterbury, there are boss stones with branches to receive the four diagonal ribs; but instead of attempting to work these branches to the same vertical curvature as the ribs they respectively receive, the branches are made straight and horizontal, and the ribs abut against them, forming a broken or discontinuous curve. Similar botchings may be observed in many early examples, and they are very curious as showing the necessity for the geometrical system that afterwards arose.

In the boss stone *h f g e*, *fig.* 13, the acute angle at *h* together with the horizontal upper surface occasion a considerable waste of material, and make it necessary to employ a much larger block of stone for the boss than is required by its mere mechanical function. These acute angles are, however, always to be found in the early examples of complex lierne vaults, as in the Canterbury boss, *fig.* 14. Afterwards an improvement was introduced into the art of stone-cutting, by which part of this useless lump was got rid of, and the back of the stone worked vertically, making its section in the form *e g z y f*. I shall reserve the explanation of this for the section on fan vaulting, to which it more properly belongs. The boss stones of the lierne vault of St. George's Chapel, *fig.* 32, are thus wrought.

Of the disposition of the liernes for the decoration of the vaults I shall say but little in this place, for the subject is sufficiently copious to form in itself a separate communication. I may, however, observe, that they are commonly so disposed as to make out a kind of star-shaped figure round each impost in combination with the ribs.

This in its simplest form may be seen in *fig.* 15, where A *d b e* is one of the rays of the star. In this example, however, the star is double, another set of longer rays, as A *b c f*, being added. Also, in *fig.* 16 (p. 27), A B C D E H is the outline of a similar star, of which G is the centre. I have elsewhere ventured to term these vaults *stellar vaults*, and have quoted continental examples of them, to which I beg to refer[19].

Besides and in addition to these stellar forms round the *springing* of the vault, the liernes are so placed as to produce other ornamental figures about *the centre* of the vault. Thus, in *fig.* 16, the same series A B C D E which forms the star round G, also represents the quarter of a cross with pointed ends, which has K for its centre; and in *fig.* 19, a lozenge occupies the centre of each compartment; while in the vaults of the north-eastern chapel at King's College already described, a symmetrical six-rayed star is formed upon the crown of the vault by the liernes.

But my reason for at present alluding to this part of the subject is to point out two sets of examples, which in opposite ways serve to show the dependence of these designs upon geometrical constructions. *Fig.* 19 is the plan of a vault (from the monument of Archbishop Stratford in Canterbury Cathedral). In this plan the usual stellar form, radiating from H, appears to be abandoned, for the liernes G F E D C B A, which ought to constitute this figure in combination with the ribs, are so placed that the regular pointed rays are lost by F E D and B C D lying each in one straight line. But when the vault is viewed in perspective (*fig.* 18), the stellar form appears, for *d e f*, which on the plan at D E F is in one straight line, is not so in the elevation, the point E being lower than F and D. The consequent depression of *e* and of the similar point *c*, restores the figure of the star when the vault is viewed obliquely, but a person standing nearly under the middle of it, and looking upwards, would then perceive the regular crossed lozenge in the centre.

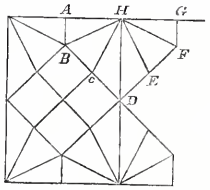


FIG. 19.

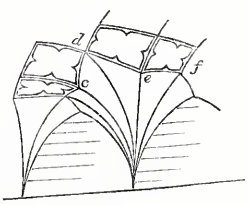


FIG. 18.

[19] Architecture of the Middle Ages, especially of Italy, p. 23.

Thus the plan is ingeniously combined with the perspective effect to exhibit the two figures. In a great number of vaults of this class apparently symmetrical shapes are shown which entirely disappear or become distorted on the plan. Thus, in Canterbury nave, the vault in perspective appears to have a regular double star on each angle, like that of the cloister vault (*fig.* 15) of the same cathedral. But upon the plan this figure is so distorted that its existence would not be suspected. This argues a great power of foreseeing the solid effect of a design, and also a practical knowledge of the liberties that may be taken by throwing the plans out of symmetry without producing an appreciable distortion in execution.

On the other hand, in a large proportion of vaults, symmetrical lines and figures are introduced uselessly into the plan, for they disappear or become disagreeably distorted in the solid effect. The choir vault of Wells Cathedral is a very striking example of this, for its plan is a regular pattern formed of diagonal lines, with four rows of square compartments at their intersections, such as would form an excellent pattern for a flat ceiling, but being projected upon the surface of a groined vault, the symmetry of the figure, upon which from its nature its beauty alone depends, is entirely lost, the squares are distorted into irregular trapeziums, some of them bending round the groins, and the meaning of the whole destroyed. But this pattern *must* have been projected from the plan by a geometrical system, for the frame of the vault is very carefully constructed of ribs and liernes, and, as far as the mechanical construction goes, is a very admirable and intricate piece of work[20].

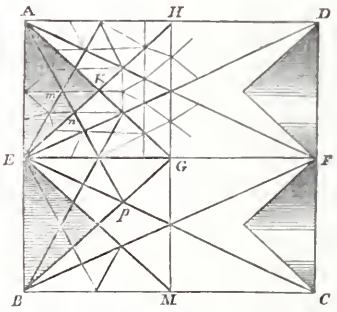


FIG. 17.

As another and more curious kind of example, let us take the vault of Gloucester choir (*fig.* 17), of which two compartments are shown in outline. This vault has two sets of ribs, namely, principal and secondary, of which the first have more mouldings than the second. I have shown the principal ribs only in the compartment EBGM, and the secondary are added in AEHG. The general form of this vault is a pointed waggon, of which HM is the ridge, and the transverse vaults of the clerestory windows enter this at a level considerably below that of the ridge.

These transverse vaults are shown upon the plan by shading. The curvatures of the ribs and liernes appear to be so carefully adjusted as to agree very

[20] There is a plan and view of this vault in Britton's Wells Cathedral.

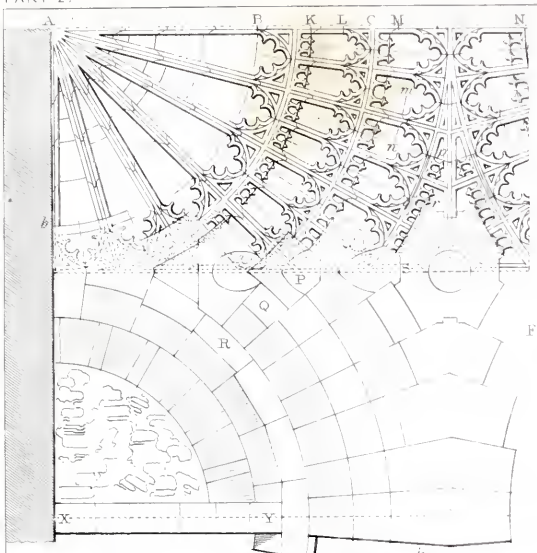


Fig. 24.

Fig. 25.

PETERBOROUGH CATHEDRAL

Scale of 0 1 2 3 4 5 Feet.

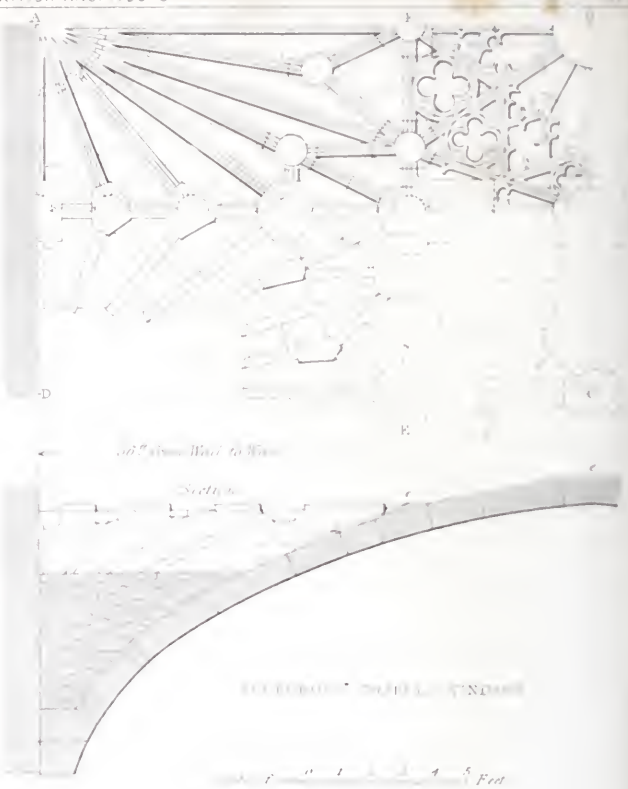
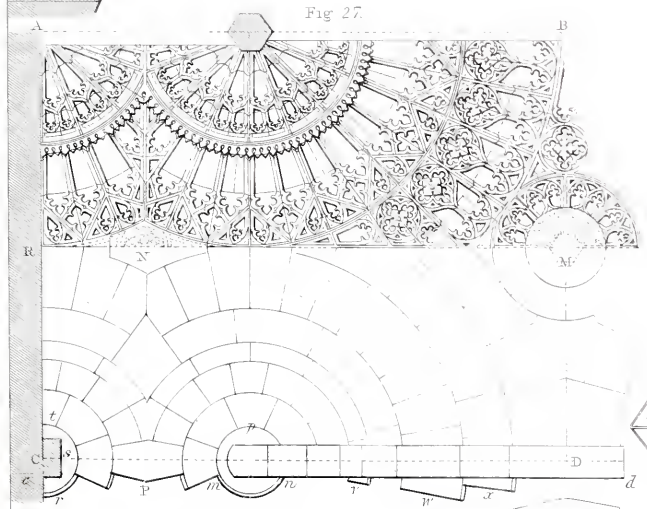


Fig. 26.

Fig. 27.



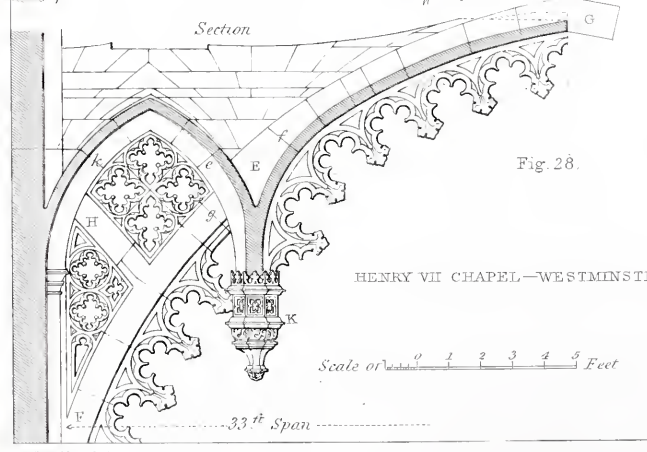
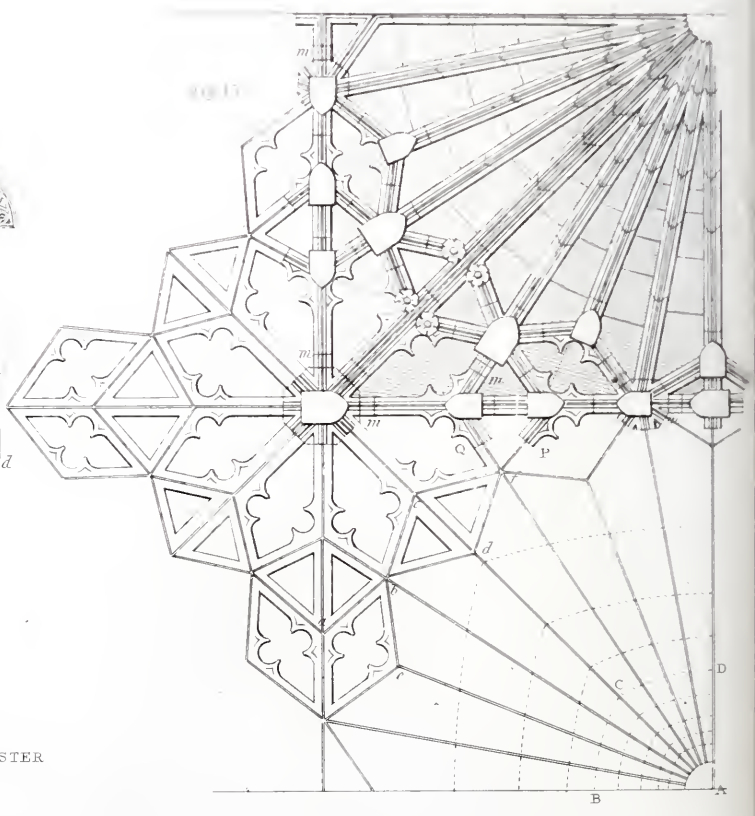


Fig. 28.

HENRY VII CHAPEL—WESTMINSTER

Scale of 0 1 2 3 4 5 Feet



CANTERBURY CLOISTER

Scale of 1 2 3 4 Feet

nearly with the surface of the great waggon vault at least. Now the plan of the primary ribs is evidently produced by drawing lines from each impost as at A to meet the centres of the ribs H G and E G, and also the point G. But the rib A *m n p* straight upon the plan, and, drawn in conformity with this system, completely loses its meaning in the solid effect; for it will be seen that it runs from A to the apex of the clerestory vault at *m*, then down again to the groin at *n*, and then up from *n* to *p* upon the surface of the great waggon vault. In execution this is an unmeaning line, and it is only with some trouble that its position upon the plan can be detected. In fact, the entire design exhibits in execution as little system as a spider's web, and yet, being erected of ribs and liernes with bosses at their intersections, must have been derived by careful projection from the plan as here shown, and the effect is after all rich and peculiar.

The vaults of the transepts of Gloucester, that of the north transept of Bristol Cathedral, and of St. Michael's Chapel at Canterbury, may be also cited as belonging to this class, as well as the now destroyed vault of the choir of York.

The mechanical construction of these lierne vaults is various. Most of them, at least the larger and simpler examples, are built exactly in the same manner as the rib vaults already described, that is, a stone framework is constructed of ribs, liernes, and boss stones, all of which are rebated for the reception of stone pannels or vaulting surfaces, which are dropped in from above. When the vaults are large and the ribs and liernes few, these intermediate surfaces are built of light rough masonry as before; but when the intervals are made smaller by the increased number of the reticulating ribs and liernes, the connecting surface becomes a mere *pannel* of one or two stones, each of which was, as I suppose, *scribed*, as a carpenter would call it, to fit the *frame*.

Fig. 15 (Plate I.) is an example of this method, from the cloister of Canterbury Cathedral.

The span of this vault is thirteen feet, the ridge ribs are level, and it approaches in effect very near to a fan vault, although it is not one, as I shall show when I come to the explanation of that class of vaults. In fact the middle plans of the spandrel, instead of being circles round the impost A as in fan vaults, are of the figure B C D. The *tas de charge*, or portion of masonry above the impost, which contains the nascent ribs in their state of entanglement, is laid in three courses, of which the lower is two feet six inches in thickness, and the others one foot three inches, and nine inches respectively. The

upper stone has inclined beds formed for each rib to spring from, exactly as I have already described the earlier vaults (page 7), and the plain portions of rib which connect this stone with the boss stones in the crown of the vault are built of voussoirs about eighteen inches more or less in length.

The bosses are so numerous, and lie so close together, that the stumps of ribs that are in one piece with adjoining ones touch for the most part, as shown in the drawing, with one or two exceptions, where small thin slices of rib are interposed; these are marked *m* in the figure. Some of the compartments are foliated, but the cusps are attached to and worked out of the boss stones. The pannels are laid in in one or two pieces, as the case may be. Their joints, which occur irregularly, are indicated by dotted lines.

In this and similar examples the stumps of ribs which spring from each boss stone are worked separate as so many branches. This is shown at the margin of the figure at P and Q. In other vaults of this class, however, the boss stones are so worked that they each contain a portion of the pannel surface between the short ribs. This is the construction of the vault *fig.* 16 (p. 27), from the gateway of Queen's College, Cambridge. Each boss includes between its branches as much pannel surface as is contained by a straight line drawn from one to the other; but for the rest the construction is the same as the above. Adjoining bosses either touch, as B and C, or are connected by short pieces, as M, N; the remaining portion of the intermediate surface, as P, Q, is a pannel dropped in from above. The lower portion of the ribs and their connecting surfaces are precisely constructed as in the previous examples.

In a third construction, however, the rib and pannel method is entirely abandoned, and the vault, the same in decorative appearance as the previous ones, is nevertheless built of solid jointed masonry, every rib stone carrying with it in one piece the requisite portion of the neighbouring intermediate surface. An excellent specimen of this mechanical construction is the vault of Henry the Fifth's tomb at Westminster; but as this method appears to have grown out of the fan vaulting, I shall proceed to that, and postpone the description of the vault in question for the present. There is also a good specimen of this construction in the umbrella-like roof of a staircase which leads to the top of the small south-western tower of Peterborough Cathedral.

It thus appears that the rib and pannel construction was finally driven out and superseded by solid masonry, although to all appearance the vaults continued to be formed of ribs and pannels as usual. Very early in the history of vaulting, the lower extremities of the pannels were made solid, as I have shown in page 7. Next, it was found simpler and stronger to work the small

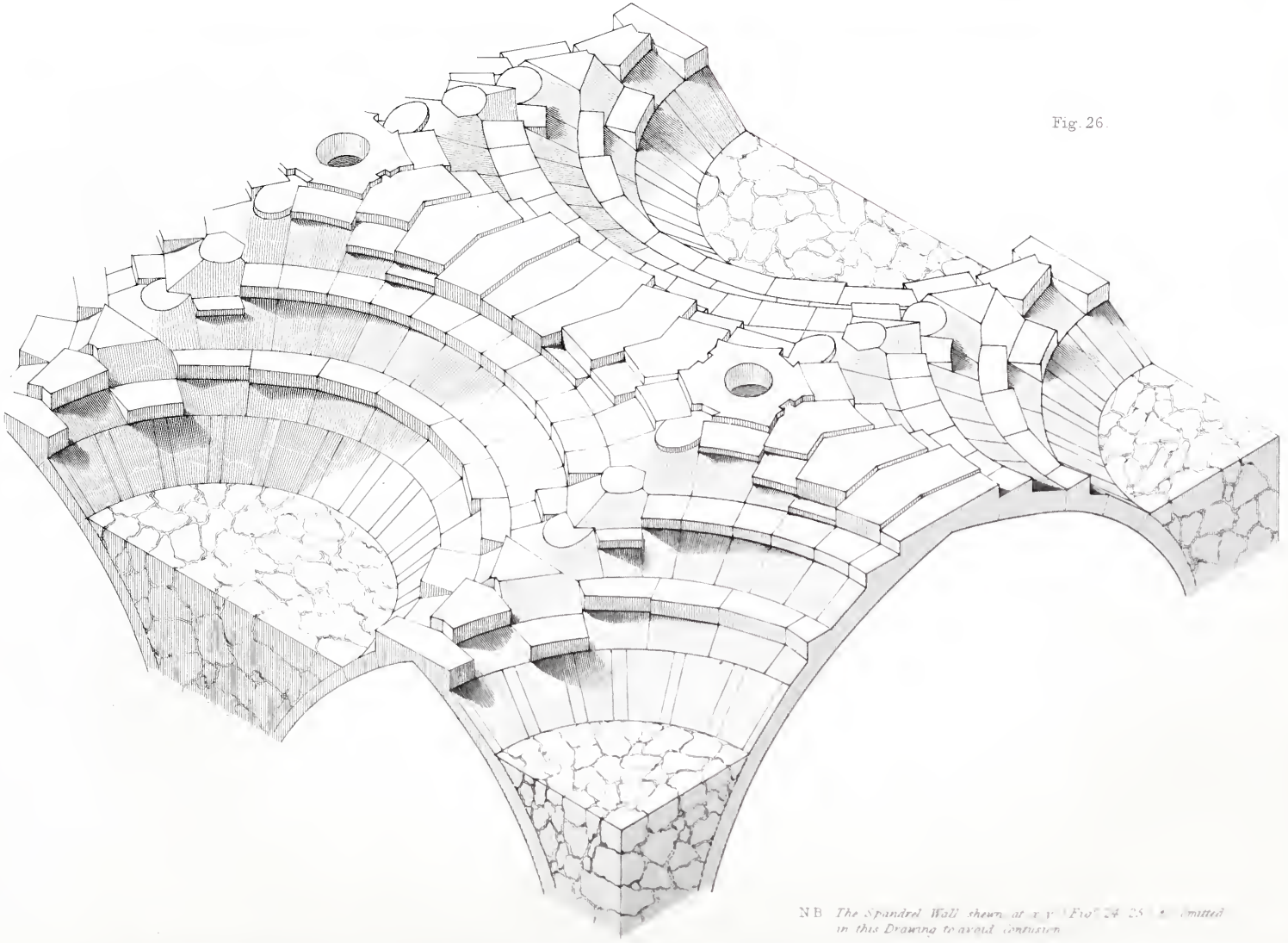


Fig. 26.

NB *The Spandrel Wall shewn at x y (Fig^s 24 25) is omitted in this Drawing to avoid confusion.*

R. Willis. del.

PLATE II

T. T. Bury sc.

FAN VAULT, EAST END OF PETERBOROUGH CATHEDRAL.

portions of pannel surface between the branches of the boss stones out of the same block, than to cut them away and drop in the pannel afterwards. Then the bosses, from the increasing complication of the patterns, began to approach so close, that it was worth while to take the pains to make them meet, and thus the crowns and ridges of the vaults came also to be built solid. Lastly, the solid construction was extended to the entire vault, and so by gradual degrees the mechanical and decorative construction of the vault, which began by being identical, ended by becoming totally different.

Section IV.—On Fan Vaults.

In fan vaults, the difficulties of adjusting the curvatures of the ribs are at once disposed of by making them all of the same curvature. We may suppose that the increasing complication of the patterns in the vaults of the kind already described, and the great number of intermediate ribs and liernes that were thus introduced, may have led to the invention of this method, by which certainly the number of templets and the difficulties were greatly diminished. The construction of these fan vaults is in all examples so nearly the same, that they seem to have proceeded from the same workshop; and it is remarkable that, at least as far as I know, there are no continental examples of them, whereas of the previous vaults there are quite as many on the continent as in England. In France, indeed, the lierne vaults are not very numerous, they are confined to small chapels, and their patterns are in general simple; but in Germany and in the Netherlands there is an abundance of them, distinguished certainly from ours by local peculiarities, but nevertheless of similar mechanical construction, and requiring the same geometrical methods.

The general construction of fan vaults may be understood from *figs.* 24, 25 (Plate I.), and 26 (Plate II.) These represent one of the most complete, which covers a kind of chapel at the east end of Peterborough Cathedral. The workmanship of this vault is the most perfect of any that I have examined. The span of King's College Chapel (forty-two feet) is much greater, but its workmanship is not nearly so good. The span of the Peterborough vault is twenty-six feet from wall to wall.

The pattern of these vaults is always a kind of tracery of the same class as the perpendicular tracery which at that period occupied the heads of windows or the surfaces of walls, the only difference being that the mullions, instead of

being parallel and vertical, are curved and radiate from an impost. Instead, therefore, of the horizontal transoms of windows, we have level circles intersecting the ribs at nearly equal distances, and intermediate rays or ribs are inserted between the principal ones. The pannel spaces into which the surface of the vault is thus divided are furnished with arch heads and foliation, exactly as the similarly produced pannels are ornamented in the tracery of windows.

I have already stated that in the lierne vaults a star pattern is commonly found, which radiates from each impost in the same way as the fans of the present class of vaults. The difference between the star and the fan is, that the star is formed of ribs, which may be and often are of different curvature, and the rays of the star of different length, but so skilfully arranged with regard to their solid effect, that although irregular upon the plan, this irregularity is not offensively perceived in the complete work.

The fan is, on the other hand, formed of ribs strictly of the same curvature and elevation, and its outline is bounded by a horizontal circular rib instead of the zig-zag line of liernes in the former vaults by which the rays of the star are pointed. The effect of the fan is that of a solid of revolution upon whose surface pannels are sunk; the effect of the star is that of a group of branching ribs. This difference of character is assisted by the mode in which the mouldings are disposed in the two cases. In the older vaults a vertical plane upon the plan line of every lierne or rib divides it into two symmetrical halves; but in the fan vaults the moulded rings and arch heads are all perpendicular to the surface of the vault. This will be more fully explained presently.

In fan vaults the quantity of decoration is so much increased, and its parts become so small, that it is no longer practicable to frame the tracery of these vaults on the rib and pannel system with liernes and boss stones, and consequently the portions near the crown of the vault, where the decoration is compressed and crowded, are always constructed of jointed masonry. But the branching ribs below the first series of arch heads are still built of long stones filled in with pannels, and the *tas de charge* from whence the ribs spring is also laid in level courses as before. There are a few exceptions to this general description; for example, the vault of Henry the Seventh's Chapel, which, however, differs in many other particulars from these fan vaults, and will be separately described. It is entirely constructed of jointed masonry without pannels. Also the vault of Islip's Chapel at Westminster is a real fan vault, but without any mixture of rib and pannel work.

In *fig.* 24 the upper half of the plan represents the lower surface of the

vault with the joints of the masonry and pattern of the tracery, and the lower half shows the upper surface of the vault with its joints. *Fig.* 25 is a vertical section through A C, and *fig.* 26 an isometrical projection of the upper surface. The portion of vault included within the spandrel A B C, consisting of plain ribs only, is constructed of rib and pannel work exactly like the older vaults; but all the remainder of jointed stonework, as shown in the lower plan. In the King's College vault, and in many others, the short straight portions of rib that lie between K and L are also constructed in separate stones with pannels dropped between[21].

The section shows that the spandrels of this vault are filled up to the level of E with rubble work, as are also the spandrels of King's College vault. In addition to this, a wall *x y* is at Peterborough added to stiffen the spandrel. This I have not seen elsewhere. Every one of the stones of the *jointed masonry* retains a portion of the horizontal *surface of operation*, which in this construction is evidently employed for the same purpose as in the boss stones of the lierne vaults. These horizontal surfaces are indicated upon the plan by the light tint, and are also shown in the section at *g*, *h*, and *k*, and more clearly in the perspective drawing, *fig.* 26.

The joints of the masonry are evidently arranged with reference to the pattern of the vault. Thus a ring of stones round A beginning at B K is made to contain all the first series of pannel heads, with the circular rib and crown of Tudor flowers. The succeeding ring from K M contains the next series of pannels, with their arch heads and the Tudor flowers above them. As to the next ring, it begins at M N, by extending across the crown of the arch; and when the stones become too large, they are divided, as at *m n*, *p q*, and *r s*, in such a manner as to interfere as little as possible with the lines of the pattern. It is remarkable that the masons of this period often place a joint in the very middle of a projecting rib, as at *p q*. As to the radiating joints, they lie in this example in the middle of the pannels, but in others not universally so. Since the disposition of the joints is thus governed entirely by the pattern of the tracery, it is clear that in setting out the moulds of the stones the *lower* joints must first have been drawn upon the plan, and then the moulds of the *upper* surfaces obtained from them by a system of projection similar to that which I have already applied to the lierne vaults and bosses.

It must be supposed that the lower surface of the stones was worked smooth, and the lesser ornamental details drawn upon this surface, so that,

[21] For the details of King's College vault I shall refer to the accurate drawings of Mr. Mackenzie, in the new edition of Tredgold's Carpentry.

for the purpose of settling the places of the joints, only the ribs and circular bands were drawn on the plan; for if the entire pattern were drawn on the plan and transferred to the surface of the vault by projection, as in the case of the complex lierne vaults, the arch heads, circular pannels, and other figures which decorate the spaces between the principal lines would be distorted after the manner of the squares in the choir vault at Wells, already mentioned. But such distortions never appear in these figures in fan vaulting, so that we may assume that these details were traced upon the lower surface of the vault stones, but that all the principal lines necessary for obtaining the form of the stones and distribution of the joints were projected from the plan. Indeed the new manner in which the mouldings are worked, namely, perpendicular to the surface of the vault, as already mentioned, shows that the patterns were now drawn upon and sunk into that surface, and not derived from the plan.

I will now explain the steps by which I suppose the shapes and moulds of the stones to have been obtained, and which in principle is the same as the method by which I have obtained the boss stones and liernes, namely, by means of the horizontal upper *surface of operation*, of which there is abundant evidence to prove the employment in all the existing specimens of fan vaulting of which the upper surface is accessible.

Fig. 21 explains this method, and corresponds in the plan of the vault to *fig.* 24 (Plate I.); the examples chosen being the stone marked P and those which correspond to Q and R on the opposite side of the ridge rib.

On the plan *fig.* 21, the ribs and circular bands being inserted, as shown by the double lines, draw A B the central line of the rib upon which the stones in question lie, and upon it draw in elevation C D, the curve of the rib, which, from the nature of fan vaulting, is the same for every rib.

The joints at the lower surface must next be drawn upon the plan, as shown by the dotted lines, due regard being had to the ornamental details which are to be subsequently added. These joints are either radial or circular, from the nature of fan vaulting. The radial joints which converge to the centre A are all in vertical planes, and therefore their places upon the upper plan or surface of operation will be vertically above and coincident with their places upon the lower surface, as at *a b* and *c d*. But the circular joints are arch beds[22], and their places upon the upper surface may be obtained from those of the lower surface by upwards and downwards projection as follows.

[22] These beds are in fact conical surfaces, which may be obtained theoretically. Draw A Z perpendicular to A B, then will A Z be the axis of the solid of revolution or *spandrel-conoid* generated by the

The circular joints intersect the line A B at the points *n*, *q*, *s*. Project these upwards to meet the curve C D at N, Q, S. Draw F M X concentric to the curve, and at a distance from it equal to the necessary thickness of the rib C D.

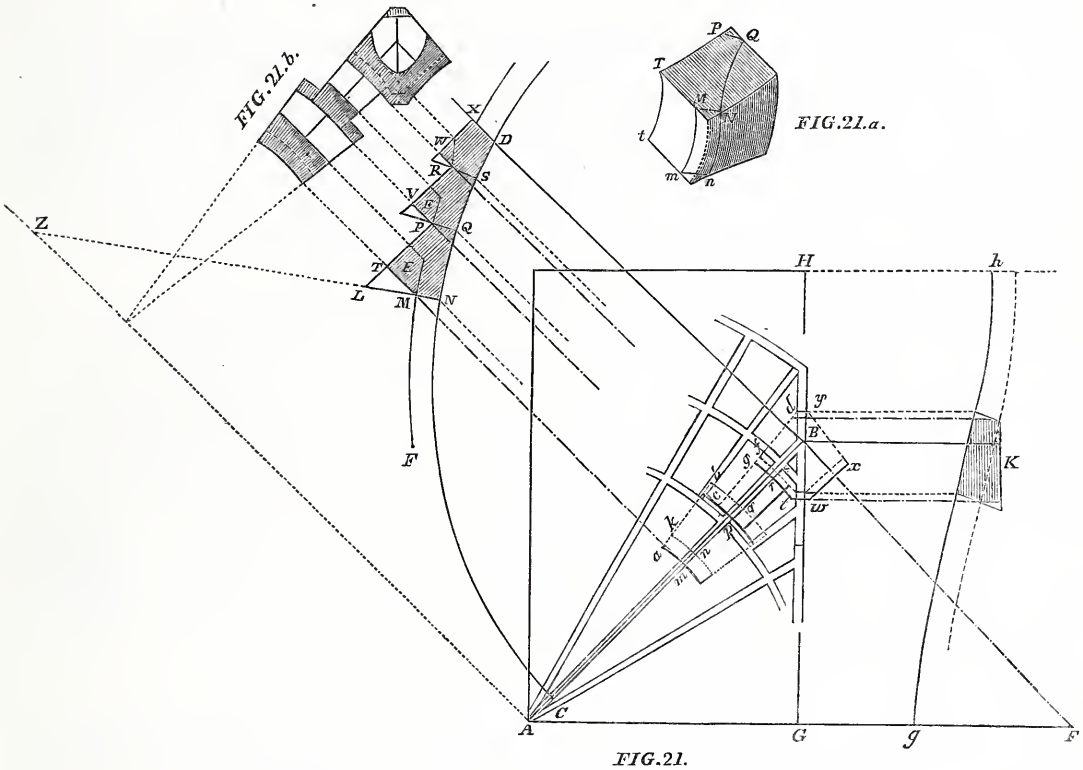


FIG.21.

From the centre of curvature of C D draw the arch joints N M, Q P, S R, intersecting their outer curve at M, P, and R; and through these points draw vertical lines M T, P V, R W, also projecting the same points downwards to the plan at *m*, *p*, and *r*. With centre A draw circular arcs *a m*, *c p*, *g r*. Thus will be obtained the plans or moulds of the upper level surface of operation of the stones N P, Q R, and the horizontal lines T P V R will be the sections of these upper surfaces.

To complete the third stone S X, however, it is necessary to draw the curve of the ridge rib; for this stone, being placed at the meeting of two ribs A B F B, and of the ridge rib G B H, resembles in this respect a boss. It is in fact upon the plan a six-sided figure, bounded by four arch joints, *g t*, *t w*,

curve C D; and M N being any given arch joint of this solid, produce it to meet the axis in Z. The bed of which M N is a section is a frustum of the cone, that would be generated by the revolution of Z N round the axis A Z.

$w\,x$, $d\,y$, and two radial joints $g\,d$, $y\,x$[23]. The joint $w\,x$ being opposite and similar to $g\,t$, the same section W S X D will serve for the two joints, but the joints $t\,w$, $d\,y$, must be obtained from the elevation of the ridge rib, which may be drawn as follows.

Since the arch ribs of a fan vault are all of the same curvature, the ridge ribs can no longer be horizontal, and their form is in fact determined by the intersections of the arch ribs, so that when the dimensions of the parallelogram which is to be covered by each severy of the vault, and also the curve of the rib, are given, the form of the ridge rib may be found. For example, as follows:—Let A B C D, *fig.* 20, be one quarter of the severy, A D A G A F A E A C the ribs branching from A, of which a K N P is the curve in elevation upon A B. A c is made equal to the longest rib, namely, the diagonal rib, A C; and the lengths of the other ribs are transferred by arcs of circles round the centre A to the points $d\,g\,f\,e$ respectively. Draw perpendiculars upon these points meeting the curve in K L M N and P, then will G be the plan of the point at which the rib A G intersects the ridge rib, and A g is equal to A G, consequently a L is the portion of arch curve occupied by the rib A G, whence g L is the height of the ridge rib at G above the impost plane. In like manner A e (equal to A E) shows a N to be the quantity of arch curve occupied by the rib A E, and thence e N is the height of the ridge rib at E. Similarly it can be shown that d K, g L, f M, e N, c P, are the respective heights of the points D, G, F, E, C, of the ridge rib. Draw, therefore, perpendiculars D k, G l, F m, E n, C p, through these latter points, producing them to A B, and also parallel lines K k, L l, M m, N n, P p, intersecting them in k, l, m, n, and p, then will the curve drawn through these points to the elevation of the ridge rib referred to A B.

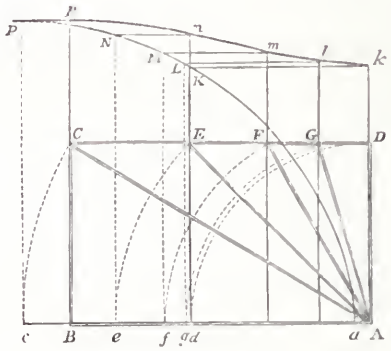


FIG. 20.

The curve so obtained being transferred to the plan *fig.* 21 at $g\,h$, the section of the stone in the middle plane of the ridge rib may be drawn as

[23] Sometimes, when the pattern of the vault admits of it, one or both of the ridge joints $d\,y$ $t\,w$ are omitted, and the stone brought to a point on the plan at $t\,w$ or $d\,y$. This happens to be the case in the stone which at Peterborough corresponds to the one I am now describing, as will be seen in *fig.* 24; but as the two joints in question are very often employed I have inserted them in this place to make the description of the method complete.

at K, by upwards and downwards projection, in the same manner as the other sections have been obtained.

In this stone the perpendicular B D X upon the intersection of the ribs corresponds to the *axis of the boss* in *fig.* 13 (p. 32).

The stone N P may now be worked as follows. Having levelled the upper surface of operation, trace upon it the upper mould which has been described upon the plan at *m a c p*, and also the arc *b q*. Work the radial joints perpendicular to this surface, and trace upon them the side mould N M T P Q. Work a concave surface also perpendicular to the surface of operation, and meeting it in the line *a m*, and a convex surface meeting it in the line *b q*. *Fig.* 21 *a* represents the stone in the state to which it has now been brought. It is viewed angularly; *t* T P is the edge of the surface of operation, N M T P Q one of the radial sides plane and perpendicular to the latter surface, and T *t* M *m* is the concave surface, also perpendicular to the upper surface. The outline of the side mould is shown traced upon the radial surface. To complete the stone, it remains to form the two conical arch beds M *m* N *n* and P Q. The latter is easily wrought, by tracing a horizontal line on the convex surface, beginning at Q, and then working away the stone in straight lines from this line to the arc already traced on the upper bed from P; or this bed may be worked by means of a bevel set to the angle T P Q, and thus the necessity for working the convex surface be dispensed with.

In like manner the lower arch bed M *m* N *n* may be wrought in two ways: first, by tracing from M the horizontal line M *m* on the concave surface, and working the bed by a bevel set to the angle T M N; secondly, by working the lower surface of the stone into a horizontal plane passing through N and parallel to the upper surface, tracing the arc N *n* upon the lower plane, and then working away the stone in straight lines from M *m* to N *n*. The bevel method, being the simplest, is most probably the one which was employed by the Middle Age workmen. The other method is more analogous to modern practice, and is susceptible of greater precision. The two arch beds being completed, the lower surface *n* N Q is easily wrought from the lower boundary N *n* to the upper boundary which passes through Q, by means of a sweep or templet whose edge is cut to the curve N Q.

A similar process will give the form of the more complex stone at the intersection B of the ribs.

In forming the boss *fig.* 13 (p. 32), the stones were worked to an acute angle as at *g h f*, by which means a superfluous angular lump of stone is left at *h*. If the upper plan of the stone had been projected as in the above method

from the point *y*, where the arch joint *f h* meets the outer curve of the rib, the useless portion *y h* z would have been saved, and a smaller stone have served the purpose. This is a more complete and scientific process; and while the angle *g h y* remaining in the Canterbury bosses and others is evidence of the ruder process, the vertical surfaces T M *m t* (*fig.* 21 *a.*), which may still be traced in the fan vaults, prove also the use of the improved method which I have just explained. In the later lierne vaults, however, this latter method is also applied to the bosses. In fact the fan vaulting was invented long after the lierne vaulting, but they continued to be practised together up to the latest period; and the improved system of stone cutting introduced by the increased complexity of the fan vaults would naturally be applied to the lierne vaults. Thus it happens that many of the later specimens of the latter are constructed with solid masonry instead of the original rib and pannel method. In the view of the roof of St. George's Chapel (Plate IV.), it will be seen that the bosses were worked vertically downwards from the plan in the same manner as the stones in *fig.* 21.

The arch joints or beds of bosses, however, are planes, but those of fan vaults ought to be conical surfaces. This is not universally the case in practice. The joints of the vault of Henry the Seventh's Chapel appear to be in many parts of the severy worked in planes. Those of Islip's Chapel are also worked in planes, as shown in *fig.* 22. This is a mere diagram of a portion of the fan, and therefore the joints are not projected over the mouldings.

The fans are in this example constructed entirely of solid masonry, and not of rib and pannel work. A B is a wall rib, A D a diagonal rib, A C an intermediate rib, and the arch joints are planes, arranged with respect to the ribs A B A C A D so as to pass respectively through the axis of curvature of each of these ribs respectively. In other words, if the vault be divided by lines A *b* A *c* drawn through the middle of each compartment, every portion which is contained between two of these adjoining lines *b* A *c* A forms an ordinary arch with plane joints. But in the lower stone or *tas de charge* the joint line runs obliquely across the tierceron, and beds are only provided for the wall and diagonal arches. Similar plane arch joints may be found in some parts of the smaller vaults at Peterborough; but the curvature of joints of this kind differs so little from a straight line, that it is not always easy to satisfy oneself which of the two is the case, unless the joints are very accessible and decidedly marked, as they happen

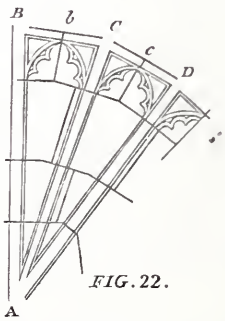
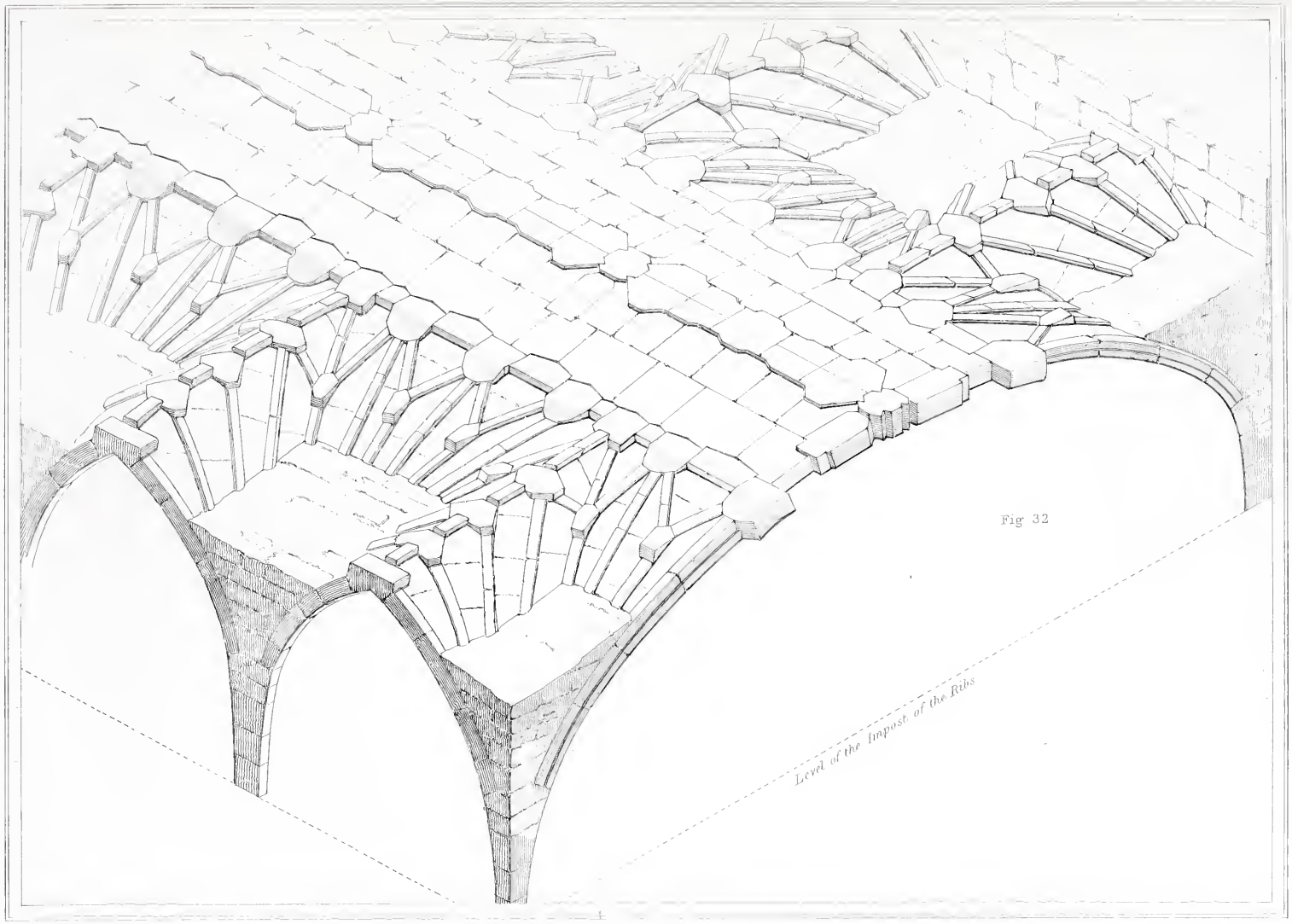


FIG. 22.



R. Willis. del. PLATE IV. T. T. Bury sc

ISOMETRICAL VIEW OF THE UPPER SURFACE OF THE VAULT OF S^T GEORGE'S CHAPEL AT WINDSOR

to be in the Islip Chapel. In the King's College vault the joints are circular, and the arch beds consequently conical.

In a similar manner the pannel surfaces of fan vaults which ought to be convex, and are so in many specimens, are wrought in planes in others, although the horizontal ribs are made circular. But in the fan vault of Wells tower and Islip's Chapel the horizontal rib runs in straight lines from one arch rib to the other, thus giving polygonal faces to the fans, and in these the pannel surfaces are planes of course.

Fig. 23 shows the arrangements of mouldings which have been already alluded to as prominent characteristics of the two kinds of vaulting. In A B a rib is shown, which is intersected in its course by two liernes at *a b c d*. The middle plane of these liernes being as usual vertical, it is plain that their mouldings cannot mitre (as it is termed) with those of the rib, because they are placed symmetrically to their own axis, while the mouldings of the rib cross at an angle which throws them on one side below, on the other above, the corresponding ones in the lierne. This is shown more distinctly in *fig.* 14 (p. 35), and leads to great difficulties in the management of the intersections of these mouldings, which are in fact generally covered by bosses that prevent their awkwardness from being discovered; and we might fancy that it was for this purpose the bosses were invented, were it not that they are employed for the intersection of the crowns of arch ribs, in which no such difficulties occur, long before the liernes are introduced. The horizontal ridge ribs, however, which are much older than the liernes, present the same kind of difficulty in their intersection with the crowns of pointed arches. To overcome these difficulties, we sometimes find, when bosses are not employed, that the mouldings of the rib are awkwardly warped and distorted at their junctions, as from *d* to *b*; also that the plain side of the lierne is several inches higher on one side than on the other, as at *a*, or else that the surface of the vault is dropped on one side to accommodate the lierne, but which introduces a similar difficulty with the rib, as at *c*.[24] Nevertheless the branching and independent character of the ribs and liernes is so intimately bound up with this verticality of their middle planes, that I cannot help ascribing one of the first departures

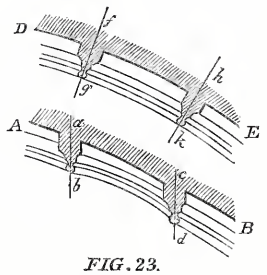


FIG. 23.

[24] This is not well exhibited in the woodcut. The plain sides of the lierne *c d* should be of equal height, and the vaulting surface raised on the right hand, and dropped on the left accordingly. The sketch A B was made from one of the liernes of the vault of Henry the Fifth's tomb at Westminster.

from the true Gothic character to the change in the method of intersecting the mouldings, which is the leading feature of fan groining.

This is shown at D E, where a rib of the same profile as A B is intersected by two others, *f g h k*, and by placing their *axes of symmetry* or middle sections perpendicular to the surface of the vault, a perfect mitring of the mouldings is obtained, and the workmanship of these mouldings is at once greatly simplified and reduced to the capacity of a much lower class of workmen. But thus the ribs and other moulded lines become at once visibly referred to the general surface of the vault and subordinate to it, decorating it nearly after the same fashion and principle as the pannels and concamerations of a Roman vault, which are in like manner sunk perpendicularly to the general surface; whereas, in a genuine Gothic vault, the real surface should be subordinate to the branching ribs, and rest upon them.

In some of the lierne vaults subsequent to the introduction of fan vaulting, the liernes are worked perpendicular to the surface of the vault, as for example in the porch of Bishop Booth, at Hereford (1516-1535).

The practice of thus working the mouldings and ribs square to the surface may possibly have originated with the makers of shrine work and small canopies, which are often ornamented with very elaborate *models* of vaults. These are beautifully ribbed into patterns, and as the entire vault is worked out of a single stone, the mouldings are naturally sunk with reference to its surface. In the larger canopies of monuments, too, a similar method is often followed. Thus the monuments of Archbishops Stratford and Sudbury, in Canterbury Cathedral, have canopies vaulted with small lierne vaults very nearly alike, but in the former the mouldings are vertical, and in the latter square to the surface. Stratford died in 1348, and Sudbury in 1381.

In all the great fan vaults, the surface of operation is reduced by cutting away a considerable portion of the stone, so as to bring it to the form which is shown at *fig.* 21 *b*, and also in the isometrical view *fig.* 26. This is effected by removing the portions marked E in *fig.* 21. The remaining part of the surface of operation retains lines drawn in the direction of the ribs, as shown in *fig.* 21 *b*, but which are not inserted in the other drawings of the complete vault, to avoid confusion between them and the joint lines.

This portion of the stone appears to have been removed to lighten it, for from the rude and irregular manner in which it is cut away, and from the remains of the vertical surfaces T M *t m* at the lower parts of the stones, it is clear that they were first worked completely into the form shown in *fig.* 21 *a*.

Vault of Henry the Seventh's Chapel, Westminster.—In this example the surfaces of operation are entirely chipped away, and the upper surface of the vault reduced to parallelism with the lower; but in one or two places these surfaces remain, apparently forgotten, and traces of them are seen in many others, so that they certainly were employed there.

The mechanical structure of this vault is different from that of the other great fan vaults, for a great arch is thrown across between each severy, and each principal fan springs from one of the voussoirs of this arch at a considerable distance from the wall. Thus each fan, instead of including, as in the usual method, half the solid of revolution, contains the entire solid, at least at the lower part. These fans are, however, met by others, which spring from the wall in the usual manner. The same principle of construction had been adopted in the vault of the Divinity School at Oxford, said to have been finished about 1480[25]. This is the earliest instance which remains at present, for Henry the Seventh's Chapel was founded in 1502. The vault of the choir of Christ's Church, Oxford, by Wolsey, about 1528, is also upon a similar principle.

Fig. 27 (Plate I.), A B C D is a plan of half a severy of the vault. The upper half of the plan shows its lower surface with the ribs and pannels, and the lower half of the plan shows the upper surface of the vault and the joints. *Fig.* 28 is a vertical section through a line *c d* close to the face of the great arch.

The great arch F E G springs from the walls at F, the joints below F being horizontal in the usual manner, and the portion F *g* lies below the vault and is visible from below. A branch arch at H again connects it with the walls, and the space between the latter and these arches is also filled up with tracery, all which serves to stiffen the free portion of the arch, and prevent it from giving way by curving inwards between F and *g*. At *g* the arch pierces the surface of the vault, and the upper portion of it E G lies above that surface, its position only being marked on the lower surface by a continuation of the hanging tracery or flowers which decorate the portion F *g*.

The voussoir E, which also carries the pendant *k*, is a very large stone, connected by the joints *e f* and *g* with the rest of the structure. *f* and *g* are the arch joints, by which it is united to the great arch; but there is also a conical surface or bed extending from *e* to *f*, and shown on the plan at *m n p*, from which the masonry of the principal fan or conoidal vault radiates upwards and outwards in all directions, until it meets the neighbouring fans along the lines D M M N and N P. A fan vault of the same section rises from a conical

[25] Chandler's Life of Waynflete, p. 140.

bed *r s t*, formed upon the surface of a stone c, which projects from the wall. This vault meets the neighbouring ones along the lines P N and N R.

The rib and pannel method is wholly abandoned in this vault, which is entirely constructed of jointed masonry, as shown in the plan. This is disposed in concentric rings round the centre of each fan, and the radiating joints are placed so as to break joint with each other, that is, so that the joints of one course fall opposite to the solids of the next course throughout. All the joints are arranged in relation to the pattern, sometimes running along the middle of the ribs so as to split them. At *v w* and *x*, the voussoirs of the great arch are made to carry the neighbouring portion of the pannels. As before mentioned, the upper surface of this vault is worked into parallelism with the lower. This gives to the upper surface a very striking and bold effect, by displaying most plainly the entire mechanical construction. Its appearance is shown in *fig.* 29 (Plate III.), which is an isometrical drawing of the vault, and which also represents it as having some portions dissected away, to show better its relation to the great arch below. The vault is very thin. The pannels vary in thickness from three to four inches, and the principal ribs project eight inches from the pannels. The great arch rises seven inches above the upper surface of the vault, and is twelve inches wide.

The fans of this vault, in fact, as far as the stone cutting and the disposition of their joints are concerned, differ in no respect from a dome of masonry, the rib and pannel method having entirely disappeared; for a dome like one of these conoidal vaults is a solid of revolution, and like it would be built of concentric courses with breaking vertical joints. The forms of the stones, however, are easily obtained by the use of the surface of operation, as already explained in the case of the common fan vaults.

I have said nothing respecting the chronology of the vaults which are the subject of this paper, wishing to confine myself entirely to the question of form and construction. The history would have led me into discussions beyond the limit of this paper, and would interfere with its purpose. However, the fan vaults form so definite a group that they present much less difficulty in this respect than the others, and I have therefore thought it better to add a few remarks upon this subject.

The subjoined list contains all the principal examples of which I am aware, and most of the smaller ones. They are arranged as nearly as possible in the order of time. The column headed Span, contains the longest side of each severy in round numbers to the nearest foot, for the purpose of showing the comparative magnitude; but as the dimensions are mostly taken from engraved

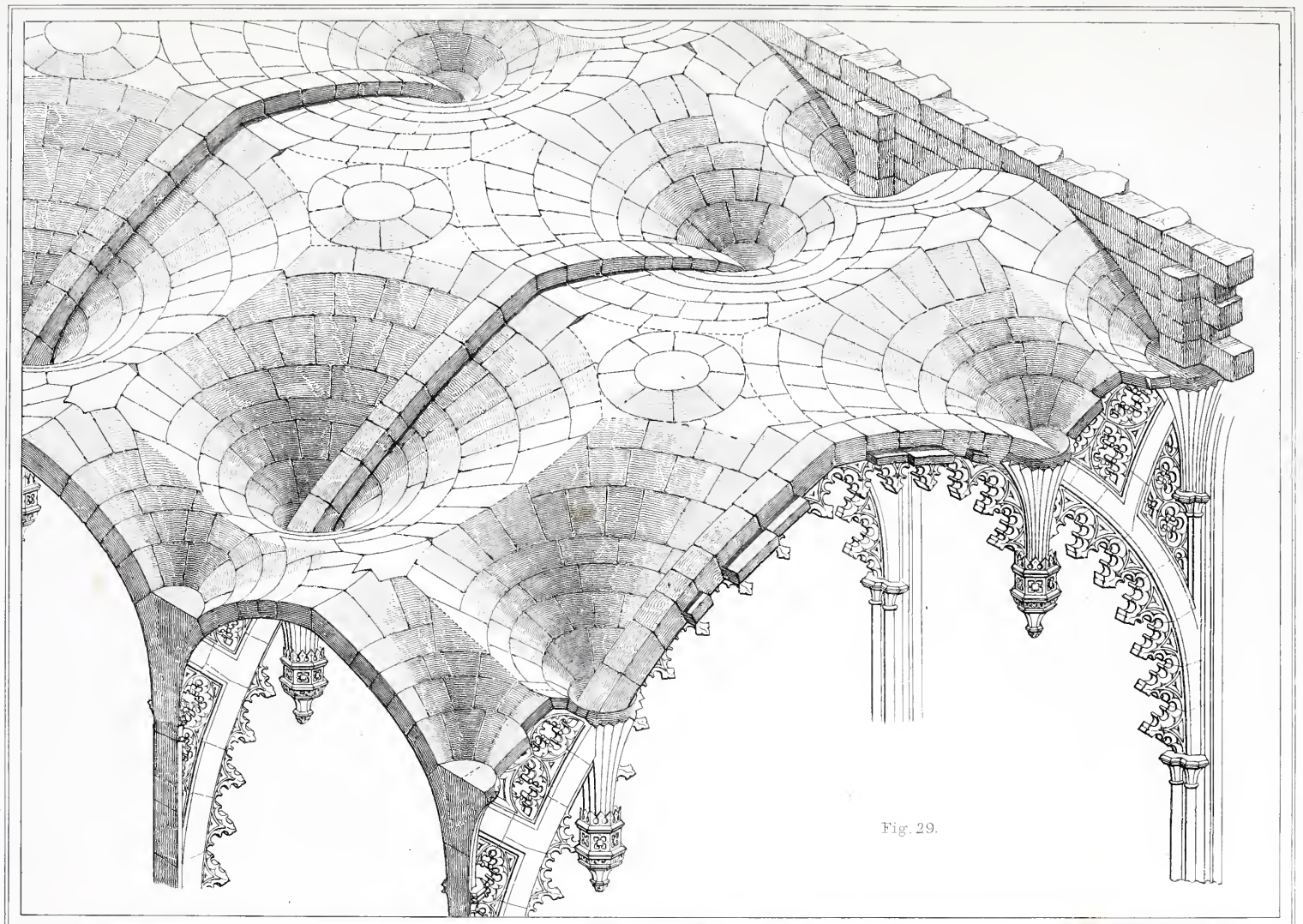


Fig. 29.

R. Willis. del. PLATE III. T. T. Bury. sc.

VAULT OF HENRY THE SEVENTH'S CHAPEL WESTMINSTER.

plans, I have not specified those dimensions in inches. It must be also understood that the list contains only genuine fan vaults according to the definition given above, namely, that the fan shall be bounded by a horizontal rib. This excludes some vaults that approach very near to fan vaults, but are in reality stellar vaults, such as the Divinity School at Oxford, and West's Chapel at Ely. In two of the examples, however, the central tower at Wells, and Islip's Chapel, the fans are bounded by horizontal polygons instead of circles. The dates in the table are those usually assigned.

Span in feet.	Example.	Date.	Reference to Engravings.
12	Cloisters, Gloucester.....(s.)	1381—1412 ...	Britton's Cathedrals.
8	Inner Porches, Gloucester	1420—1437	
7	Vault in All Souls, Oxford .....(s.)	1437—1444 ...	Pugin's Examples.
8	Vault in St. John's, Oxford .....(p.)	1437—1444 ...	———
10	Beaufort's Chantry, Winchester .....(s.)	about 1445	Britton's Cathedrals.
18	Dean's Chapel, Canterbury .....(s.)	1449—1468 ...	———
8	Chapels of Lady Chapel, Gloucester	1457—1472	
8	Stanbury Chapel, Hereford .....(s.)	1453—1474 ...	———
12	St. George's Chapel, Windsor, side aisles ...(s.)	after 1475.....	Britton's Antiq.
37	Central tower .....(p.)		
9	Waynflete's Chantry, Winchester.....(p.)	1486	Britton's Cathedrals.
15	Alcock's Chapel, Ely.....(s.)	1488	Bentham or Miller's Ely.
11	Islip Chapel, Westminster	about 1500.....	Neale's Westminster.
31	Bath Abbey Church .....(p.)	founded 1500...	Britton.
34	Henry VII. Chapel, Westminster.....(p.)	founded 1502...	Cottingham or Neale.
	Chapel in Cirencester Church.....	1508 (upon the vault).....	———
25	Central Tower, Canterbury.....	1495—1517 ...	———
26	East end of Peterborough Cathedral.....(p.)	1440—1541 ...	Britton's Cathedrals.
14	Audley Chapel, Hereford.....	1492—1525 ...	———
44	King's College Chapel, Cambridge.....(p.)	1513	Britton's Antiq.
7	Redmount Chapel, Lynn .....(s.)		
18	Hampton Court Gateway .....(s.)	after 1520	Pugin's Specimens.
18	St. Laurence Chapel, Evesham .....(s.)	1513—1539 ...	Rickman's Gothic Arch.
8	Salisbury Chapel, Christchurch, Hampshire (p.)	1540	Ferrey's Christchurch.
10	Cloister, St. Stephen's, Westminster.....(s.)	1526—1547 ...	Britton's Houses of Parl.
30	Central Tower, Wells.		
	Staircase, Christchurch, Oxford.....	1640	Ingram's Memorials.

The cloister of Gloucester is the earliest example, but the date of this is rather uncertain. The work is usually attributed to Abbot Froucester (1381—1412), but apparently upon no better foundation than tradition. Leland says, "These notable things following I learned of an ould Man made lately a Monke of Gloucester. . . . Abbot Froucester made the Cloyster, a right goodly and

sumptuous peice of Worke" . . . (Itinerary, vol. iv. fol. 172*a*). In the account of this cathedral in the Addenda to the Monasticon (vol. i. p. 995), the cloister is mentioned, but not assigned to any founder. It was probably carried on gradually through a long period, as it exhibits changes of style. There are also at Gloucester two examples of designs for fan vaults of remarkable construction. First, the vaults of the north and south chapels, which are annexed to the Lady Chapel, founded by Abbot Hanley (1457—1472). These are alike, of small span (eight feet), of excellent workmanship, and are genuine fan vaults, but the fans abut against a flat ceiling, decorated with tracery, in a row of wheel-like compartments, which extend from one end to the other of the vault, and also between the fans themselves laterally. The tracery of the fans is also different from that of the other specimens of the list, being much richer and more elaborate. Secondly, the great western door and the north-eastern door of the cloisters in the north side aisle of the nave are furnished with internal porches, in which the principle of fan vaulting is applied with great ingenuity. The door is a folding door in two leaves, and its upper edge is cut to fit the head of the archway which receives it. A *quarter-fan* on each side constitutes the vault of the porch, the fans each springing from a single shaft. The hinges of the doors are let into these shafts in such a manner that the door when opened revolves round the shaft as an axis, and consequently the arch-shaped head of the door exactly circulates about the fan which it fits, and from every point of whose surface its edge is at a small equal distance in all positions. The sides of the porch are also exactly of the same shape as the leaves of the door, so that when the leaves are opened they may be laid flat against these sides, which they exactly fill. The consequence of the employment of quarter-fans is plainly that the inner opening of the porch is square-headed, and this is filled up by a four-centred arch with open tracery in the spandrels. The entire composition is a most original, and, as I believe, unique application of this species of vault to the mechanical contrivance of a door; for whether the door be open or shut, it finds an exact recess to receive it, and in its motion about its hinges its upper edge exactly represents the geometrical generation of the solid of revolution which is employed for the vault above it[26].

The description of a fan which I have given in page 44—that it resembles

[26] The plan both of these vaults and of the chapels just described may be understood from Carter's large plan, published by the Society of Antiquaries, and may also be traced, but with some difficulty, on account of the small scale, in Britton's Gloucester.

The west front, and consequently the porch in question, has been attributed to Abbot Morwent (1420—1437).

a solid with sunk pannels rather than a ribbed vault—is more prominently the case in these Gloucester vaults, the earliest of the series, than in their successors; for the only rib mouldings that rise from the abacus are the wall ribs and the transverse rib, and the remainder spring from arches which branch from these in succession, forming pannels, and completely depriving the vault of its proper decorative construction. This management gives a much greater appearance of novelty and originality to these specimens compared with lierne vaults than even the later fan vaults possess, and makes it the more probable that they were the first fruits of the new contrivance.

But indeed, through all the perpendicular portions of Gloucester Cathedral, there runs a vein of invention that marks them as the work of a series of bold and original geniuses, any one of whom were capable of making so great a step in masonry as the invention of fan vaulting, the more especially as the elaborate designs of their lierne vaults, and the general management of the mouldings and tracery of this building, show the masons to have been perfect masters of the art of stone cutting, and to have sought out all occasions to display their power over it in quaint conceits and intricate interlacings and combinations of form. I know the danger of indulging in such speculations, but I think it is not too much to suppose that a peculiar school of masonry was established in connection with this building, and to this I should be well content to assign the invention of fan vaulting.

On the whole, we may fix the introduction of fan vaulting in the first quarter of the fifteenth century. The first work of considerable span is the Dean's Chapel at Canterbury annexed to the north-west transept; this is the known work of Prior Goldston the First, who was elected in 1449, and died in 1468. In the Obituary, the chapel is described as having a stone vault of elaborate construction: "Capellam cum testudine lapideâ valde artificiosâ." (Wharton's Anglia Sacra, vol. i. p. 145.) The work of St. George's Chapel at Windsor proceeded through a long series of years, and its principal vault is not a fan vault; but the side aisles have small fans, and the central compartment or crossing also has a genuine fan vault of large size, erected in 1528[24]. The great works of known date, namely, the central tower of Canterbury, King's College Chapel, Henry the Seventh's Chapel at Westminster, and Bath Abbey Church, are all about 1500.

FIG. 20. b.

In many of these vaults the plan of each severy is an exact square. In this case the fan is a perfect quadrant (*fig.* 20 *b*), and the space A

[24] Vide Note at page 60.

at the crown of the vault is occupied by tracery commonly formed of one or more circles. The ribs are generally stopped at the circular boundary of the fan, and do not pass beyond it into this central tracery as they do in the larger examples (as *fig.* 24). But in these square plans the principle laid down at the beginning of the section, that the ribs are all strictly of the same curvature, must be held to apply only up to the altitude of the circular ring. There is generally no ridge rib introduced into the pattern of the tracery in A, and this space is either perfectly flat, as in the specimens already described at Gloucester and in the vault at All Souls (Pugin's Examples, vol. i.), or else is slightly domical, as in the vault of Hampton Court gateway (Pugin's Specimens, vol. ii.), so that in fact no ridge appears in the vault. When the domical form is carefully adjusted to that of the fans, so as to produce a continuity of curvature from the fans to the central space, the resulting vault is exceedingly rich and elegant; but when the fans abut against a flat ceiling, they are reduced in the decorative construction of the vault to mere corbels sustaining a slab.

In large specimens the square severy would increase the magnitude of the fans inordinately, and hence apparently the parallelogram was employed. But in such vaults the ribs are of the same curvature to the apex; the ridge is marked by the same moulding as the other ribs, and is necessarily of the form given in *fig.* 20 (p. 48), convex downwards. This imparts a certain heaviness of effect to the vault, which is partly redeemed by the exceeding richness of the tracery employed to decorate the surface, but which in my opinion places these compositions in architectural merit considerably below the complex lierne vaults which they superseded. The contrast in effect between the square plan and parallelogram for fan vaults may be seen at Peterborough, where some of the compartments of the vault already quoted are of smaller span and square. In the table the square examples are marked (s.), and the parallelograms (p.).

A few fan vaults are constructed upon an apartment with a polygonal plan, as the Audley Chapel at Hereford, the Chantry Chapel in the cloisters at Westminster, the chapels of Urswick, Beaufort, and Lincoln, annexed to St. George's Chapel, Windsor, and the east end of Henry the Seventh's Chapel. The Audley Chapel at Hereford having a small span (thirteen feet six inches) and being semihexagonal, the fans are reduced to a small size with respect to the entire vault; their radius is only two feet ten inches. They surround a central ring of masonry of about four feet radius, which is formed into a very flat dome, whose curvature unites but clumsily with that of the fans. This vault being small, is wholly built of jointed masonry. The fans are formed of four stones each, one below and three above. The vault of Canterbury central tower is a

complex fan vault, having a fan in the centre of each wall as well as in the corners. There is a bell hole in the middle. This is a capital piece of workmanship. Its upper surface is accessible, and exhibits the flat surfaces of operation upon the ridge stones, but the masonry of the central portion is covered by a brick vault, apparently intended to stiffen it. The lower portions of the fans are of rib and pannel work as usual.

Vault of St. George's Chapel, Windsor.—This is a very singular vault. *Fig.* 30 (Plate I.) represents half the plan of one severy; the upper half of the plan shows the lower surface and the position of the joints with respect to the pattern, and the lower half of the plan shows the upper surface of the masonry. *Fig.* 31 is the section through DC. The portion of vault AFDE is a lierne vault with bosses of the ordinary kind, constructed entirely of rib and pannel work. The bosses, however, are not made with branches to receive the ribs, but like those of *fig.* 16 (p. 27), in irregular polygons, including a portion of the vaulting surface. Their upper surfaces are left horizontal as usual. The crown of the vault, of which FEBC is one half, is of a totally different construction; it is built of solid jointed masonry in large slabs, and is merely a portion of a waggon vault of very obtuse angle, as shown in the section from *e* to *c*. This difference of construction in the two portions of the vault, as well as the level surfaces of operation of the boss stones, will be perhaps more easily seen in the isometrical projection *fig.* 32 (Plate IV.), which represents the upper surface of the vault, but is dissected at the sides and end to show the relation of the upper and lower surfaces.

Mr. Rickman's description of this vault is so excellent that I cannot do better than quote his words. "The roof of the nave and choir of St. George's, Windsor, is very singular and perhaps unique. The ordinary proportion of arches and piers is half the breadth of the nave; this makes the roof compartments two squares: but at Windsor the breadth of the nave is nearly three times that of the aisles, and this makes a figure of about three squares. *The two exterior parts are such as, if joined, would make a very rich ribbed roof;* and the central compartment, which runs as a flat arch, is filled with tracery pannels of various shapes, ornamented with quatrefoils, and forming two halves of a star; in the choir the centre of the star is a pendant. This roof is certainly the most singular, and perhaps the richest in effect of any we have; it is profusely adorned with bosses, shields, &c."[25]

I may add, that the general form of the vault, like those of the choirs of

[25] Rickman's Attempt to discriminate, p. 104.

Gloucester and Wells, is a waggon vault, whose lateral or transverse vaulting cells enter it below its crown.

The contract for erecting the vault of the choir has been printed, amongst a great variety of interesting documentary notices relating to this building, by Ambrose Poynter, Esq. in his elaborate Essay on the History and Antiquities of Windsor Castle [26]. In this contract, dated 1505, J. Hylmer and W. Vertue agree, "in consideration of the sum of 700*l.* to build with freestone the roof of the choir . . . containing seven severeys, in the same manner as the roof of the body. . . . Provided always that the principal keys of the said vault, from the high altar down to the king's stall, shall be wrought more pendaunt and hollower than the keys of the body of the chapel . . . and all the other lesser keys to be wrought more pendant and hollower than the keys in the body of the chapel, . . . all which works are to be finished at Christmas, 1508." It appears also from the same authority, that the vault of the nave had been recently completed at the time of making this contract, as the arms of Dean Urswick are displayed upon it.

The drawings in Plates I. and IV. were made from the vault of the choir, the upper surface of which happened to be accessible at the time of my visit. But as access could not be had to the central pendant below, I have omitted it in the section, consequently in this respect the drawing resembles the vault of the nave. This pendant is hollow, and complicated in structure. The central stone projects downwards very considerably from the surface of the vault, and receives the feet of twelve small ribs, which rise from it to meet the vault. The joints of the central portion of the vault are evidently disposed with careful regard to the pattern of the tracery; but as this is a waggon vault, and very nearly flat, the forms of the stones could have been easily obtained from a plan of the actual surface, or perhaps was drawn upon a boarded centering.

[26] Prefixed to "Illustrations of Windsor Castle," by the late Sir Jeffry Wyatville, R.A. 1841. In this Essay, the date 1528 is assigned to the fan vault of the central compartment or crossing, and 1537 to the fan vaults of the side aisles of the choir upon heraldic evidence.

Additional Remarks to Section II. on the Curvature of the Ribs.

Since writing the above paper, I have had an opportunity of examining the vaults of the cloister of Norwich Cathedral, which appear to me to furnish so excellent an illustration of the remarks in page 19, &c. upon the attention paid by the Middle Age architects to the form of the spandrel solid, that I have thought it worth while to add the result of my observations.

The third volume of Britton's Antiquities contains an excellent description by Mr. Repton of this cloister, with ample illustrations; and in the Norwich Cathedral (p. 38) are additional remarks, and a passage quoted from the Itinerary of William de Worcestre (pp. 302, 305), to which I beg to refer.

I shall merely remark that the cloister is the work of successive periods, but that the intention of the successive architects was evidently to make their continuations assimilate with the beginning; in which they have so well succeeded that at the first glance the entire work appears to be of one design.

This expression of uniformity is principally due to the employment of single simple shafts with base and capital in lieu of mullions throughout the tracery; for the pattern of the latter varies, and assumes in turn the peculiar fashions, geometrical, flowing, and perpendicular, that belong to the age in which each was erected. But the external arch which contains the tracery is of the same figure throughout.

I am informed by one of the canons residentiary, who has taken much pains in the investigation of matters relating to the structure of the cathedral, that the outer wall of the cloister is Norman, so that in all probability an early cloister (perhaps of wood) existed previously to the present one upon the same site, and was replaced piece by piece by the latter, as funds or convenience permitted.

The vaulting throughout is of the same plan, namely, each severy is nearly a square, there are transverse, diagonal, and wall ribs (the latter term also including the rib which lies next to the tracery), and one tierceron between each, so that the plan resembles that of the example in *fig.* 10 (p. 19), differing only in the proportions of the severey. The ridge ribs are horizontal. The curvature of the ribs, however, is different in the different periods, and it is to the variations in this respect that I wish, in the present article, to direct attention.

The oldest vaults are the central severeys of the east walk, with which, according to W. de Worcestre, the work was commenced, in 1297; the south walk appears to be the next, and the whole of its vaults have the same character, but differ from the former. The west walk, which is also uniform in character, is the next in order; and the middle compartments of the north walk are, like the tracery which accompanies them, of decidedly Perpendicular style, and correspond to the period (1430) at which, the same author tells us, the cloister was completed. With respect to the extreme compartments of the east and north walks, the character is far less decided, and requires a farther investigation, which I have not upon this occasion had time to carry out. The account given by W. de Worcestre contains a history of the work, with the names of those who carried it on; but there are some difficulties in the application of these particulars, and he has only furnished the dates of the beginning and end of the work, as above quoted. I am inclined to think, from remaining appearances, that the vaults were in some parts left unfinished for a long time after the walls were completed, and that only the *tas de charge* was built, as we commonly find it even now in other buildings; for the curvatures of the ribs at the springing show traces of having been changed to accommodate the new fashions which had arisen when the ribs and vaults were added. For our present purpose, however, I shall select four examples, one out of the middle of each walk, the character of which is decided, and which will stand in order of time thus:—

(1) East, 1297. (2) South. (3) West. (4) North, 1430.

The dimensions and form of the ribs in these four compartments were accurately measured.

The curvatures were obtained in the following manner. (Vide *fig. B.* p. 30.) A rod three feet in length had a plumb line suspended from its upper end. The lower end of this rod was placed upon the abacus and close to the springing of the rib whose curvature was to be measured, as at M. The upper end was brought into contact with the same rib as at *d*, so that *d* D represents the position of the plumb line. The horizontal distance M D (the versine of the arc M *d*) was then measured, and thus the position of the point *d* of the arch determined[27]. Evidently any number of points in the arch may be determined in the same manner, by applying a series of rods of known lengths, as one of four feet from M to *c*, another of five feet from M to *b*, and so on. But if the rib consist of a single arc of a circle, one such measurement is sufficient, provided

[27] For *d* is the apex of a right-angled triangle, of which the hypothenuse M *d* is known, and also one side, M D, therefore the triangle is given.

the height of the crown A *a* can be measured, which is easily done, especially where the ridges of the vault are horizontal, and the altitudes of all the ribs consequently alike, as in this Norwich cloister. For the height of the wall rib is easily obtained, and serves for all. And since the spans of the ribs are all known from the plan, we have thus three points, M, *d*, *a*, given in position for each rib, from which, when laid down to scale upon the drawing board, the centre and radius of the arc can be found.

This method of measuring the curvatures has many advantages for travelling observations, for it requires merely a ladder to reach the impost, and can be carried on without help. Also a slight deviation from the horizontal position of the measuring rod M D produces no appreciable error in the result. If on account of the distortion of the rib from settlement, which is always more or less to be expected in Middle Age work, the radius determined by this method should not be very accurate, it at least gives very precisely the middle plan of the spandrel from the very nature of the process. And besides, the point *d* is contained in the *tas de charge*, which, being constructed of solid masonry, is not liable to suffer from settlement in a way to alter the curvature of the ribs, whereas any settlement of the shell of the vault changes the form of that portion of the ribs which lie above the solid masonry, so that we can only depend upon the *tas de charge* for giving us the original curvatures. But the spreading of the walls and piers, by throwing the *tas de charge* out of the perpendicular, will of course affect the accuracy of the versine M D. To get rid of this source of error, I measured these versines at every one of the four corners of the severy in each of the examples, and took the mean of the four that belonged to each rib. For the most part, however, I found but little difference. However, for accurate results, observations should also be made with rods of two and four feet. A rod greater than five feet cannot be managed in this way without assistance. Care must be taken that the plumb line be suspended from that corner of the rod which is placed in contact with the rib.

The following table contains the spans of the wall and transverse arches, and the altitudes of their crowns respectively; also the versines (or distances M D) measured as above described, and the radius of each rib determined by the drawing board, upon which the points were laid down to a scale of one inch to the foot. The small figures which accompany the radii show the distance of each centre *below* the impost plane in inches and tenths.

The principal object of this table is to give the form of the middle plan of the spandrel solid, and the accuracy of this result may be relied on. The radii are of course only determined approximately, for want of a sufficient number

of points in the ribs. One obvious source of error in this case is the assumption that the ridge rib was intended to be horizontal, for as one of the points through which the arc passes is laid down upon the assumption that the height of all the ribs in the severy are alike, it is plain that if this were not the case the error would affect the radius. However, the radii here given will produce vaults having as nearly as possible the same form of the spandrel solid as those from which the measurement was taken, which appears to me to be the most important point. In fact, at present the crowns of the vaults in the eastern walk have sunk about three inches, and thus disturbed the horizontality of the ridge; but the form of ridge so produced is so irregular and so different in the different compartments, that it is evidently the result either of bad workmanship or of settlement, and not of design. On the other hand, in the west walk, the crowns of the vaults are slightly raised, and this I suppose to be intended to allow for the effect of a similar settlement, for it is not considerable enough to be intended to give a domical form. These circumstances have been duly allowed for in determining the radii. The transverse, tierceron, and diagonal arches of the north walk are, however, four-centred, and I was unable for want of time to determine with proper accuracy the radii of their upper circles or the proportion of the two.

NORWICH CLOISTER.	East walk.		South walk.		West walk.		North walk.	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Span of wall arch	11	11.3	12	4.3	12	1.5	12	8.2
Span of transverse arch	12	4	12	1.4	11	11.5	12	6.7
Altitude of crown above impost	7	7	7	3	7	3.5	7	6
Versine of wall ribs		7		6.4		7.3		7.5
——— transverse ribs		7		7.4		8.4		8.1
——— tierceron ribs		7.4		8.8		9.6		8.1
——— diagonal ribs	1	0.4		11.7		11.2		8.1
Radius of wall ribs	7	10 | 0	7	1.5 | 2.5 above	7	5 | 0	7	9 | 1.5
——— transverse ribs	7	10 | 0	7	5 | 0	7	11 | 4.5	6	7 | 0
——— tierceron ribs	7	10 | 0.2	7	11 | 6.5	8	2 | 8.5	6	7 | 0
——— diagonal ribs	9	4 | 21	8	8 | 16.5	8	8 | 15	6	7 | 0

Fig. 33 shows the form of the middle plans of the spandrels in the four selected examples, obtained from the curvature of the ribs by a construction similar to that of *fig.* 10 (p. 19). In the east walk, marked E, AD AD are the diagonal ribs, AT the transverse rib, AW AW the wall ribs, and the inter-

mediate lines the tiercerons. The dots at the extremities of these lines show the points at which the fillets of the ribs pass through this middle plan, and it will be seen that in this case the points W D D W form a rectangle or double square, and that T is on the side of this rectangle; but the tiercerons retire slightly within it. The appearance of this spandrel solid is that of a mass decidedly rectangular in its horizontal sections, but the angles of which are rendered more prominent by the retiring inwards of the tiercerons. S shows the middle plan for the south walk, to which no letters of reference are added, as it is in general system exactly like the preceding. In this vault the diagonal, wall, and transverse ribs still form a square mass, but the tiercerons advance beyond this mass instead of retiring within it, thus giving an imperfectly polygonal character to the whole, or rather constituting a double polygon with unequal angles.

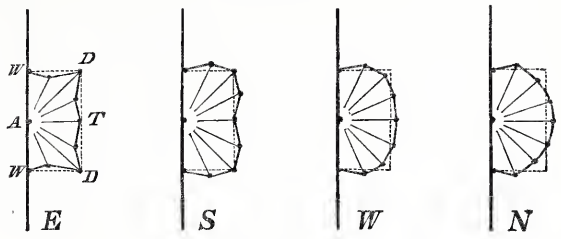


Fig. 33.

In the middle plan for the west walk, W, the diagonal rib retires within the rectangular form, and the transverse advances beyond it, so as to give a completely polygonal figure to the mass in its horizontal sections, but yet to make a polygon with unequal angles. This is a very favourite section for vaults of this period. But in the north walk the ribs (with the exception of the wall rib) are semi four-centred arches, having lower circles of the same radius, and consequently the middle plan N (taken through these lower circles), is an equiangular polygon. But as the curvature of the wall rib is greater than that of the others, its position in this section is thrown nearer to the centre, and this, by causing the vaulting surface to meet the wall at an acute angle, relieves and detaches the entire spandrel from the wall in a very bold and striking manner. The same effect will be observed in the two previous examples S and W.

It thus appears that the form of the middle plan changes by gradual succession from a square to a polygon; and as the three first examples consist of ribs of a single arc, these changes of form are all brought about by varying and altering the radii and the positions of the centres of the respective ribs.

Similar forms to all these may be found in cotemporary vaults, but it rarely happens that they occur in a series and in a work of which the general uniformity of design is manifestly preserved, so that the changes may be regarded in the light of embellishments or as the modern improvements of their day. In this respect the Norwich cloister is exceedingly valuable, by enabling us to

discover many of these improvements which it is more difficult to pick out from examples complete in the character of their own age.

A walk round the cloister will at once show, by bringing the various forms into direct comparison, how much influence the form of the spandrel exerts upon the character of the work; and upon considering the various methods by which the different radii and curvature of ribs in a vault might have been determined, and the probable motives for the different forms they are found to have assumed, I cannot discover any that have a greater appearance of probability than that of giving a certain form to the spandrel solid; for the shape of this, as determined by its horizontal sections, is so obtrusive a characteristic of every vault, and the variations of it appear to succeed each other so regularly, that I cannot suppose them to be accidental. Besides, the motive thus supplied for changing and adjusting the curvatures is of so practical a character and produces such tangible results, that it is much more likely to have been the true one than any occult numerical or geometrical relations between the radii of the several ribs. How easy it is, for example, in looking at any given vault with a view to copy it, to observe that its diagonal rib is too prominent, and therefore requires its centre to be thrown higher up or its curvature increased in order to make its middle points retire inwards, and this is precisely what has happened in the successive compartments of Norwich cloister.

Analogous changes of form constitute in effect the materials for a history of architectural decoration in general. Whatever propriety or beauty a given form may possess, we find that, by long continued use and multiplication, it palls upon the eye and requires change. The very characteristic by which it pleased the most, and which was nurtured and developed by every possible adjunct, will be in the next age softened down and subdued to make way for the prominence of some other, which was once in the same manner avoided or made subordinate. So in the series of spandrels we are now considering, the square section at first pleased the eye, and was rendered more prominent by the retirement of the tiercerons; but in the succeeding specimens this effect is gradually softened down until we obtain an equiangular polygon. But there are also mechanical reasons, as well as those derived from beauty of form, that may account for the growing preference for the polygonal section; for in the latter forms (as also in the fan vaults) the horizontal sections constitute arches that oppose the rising of the haunches of the ribs, and thus the ribs mutually stiffen each other through the intervening surfaces. This is not the case in vaults of a square section, in which the transverse rib receives no such assistance from the diagonal. It would lead me, however, far beyond the proper limits of this

paper were I to enter into mechanical considerations, which I have hitherto avoided.

I have said that the spandrel is detached from the wall by so managing the curvatures of the wall rib and first tierceron that the vaulting surface may meet the wall at an acute angle. The beauty and effect of this may be understood by looking at the opposite effect in the vault of the cathedral. This is a lierne vault of elaborate pattern, but of very rough workmanship. The curvature of the ribs is rude and broken, and displays so little management that I am tempted to believe the vault to have been wrought out by country masons with very little or no geometrical knowledge or system. The wall rib, instead of rising upon stilts and retiring, as in most clerestory vaults, for the purpose of making way for the window, is, on the contrary, an arch of a lower crown than the ridge of the vault, and is very straight-sided and misshapen in form. The transverse ridge rib rises considerably in the middle, and is curved so as to form a real segmental arch, and the middle plan of the spandrel is nearly a semicircle. The effect of these arrangements is that the spandrel seems to adhere timidly to the wall instead of springing boldly across the space, as in the vaults of the cloister.

The vaults of St. Mary Redcliffe, at Bristol, especially those of the north transept, are very striking examples of the lightness and boldness of character that may be given to a vault by setting back the vaulting surface where it meets the walls.

In the diagrams, *fig.* 10, p. 19, and others of the section on curvature, the ribs are represented by mere lines, which lines are actually the lower fillets of the ribs. Thus all that has been said of the middle section of the solid must be understood of an imaginary surface stretched from the front of each rib to its neighbouring rib, which is in truth the actual effect produced by the group of ribs upon the eye. And the horizontal section may be easily drawn when the curvatures are given, by means of *fig.* 10. This diagram, as explained in its place, is intended to give the curvatures after the middle plan has been drawn, but will easily furnish the reverse process; for let the plan of one of these Norwich vaults, for example, be drawn, and the elevations of the ribs inserted as in the figure by help of the table (p. 64) of radii; then to obtain the section of the solid at any required height R *s*, we have only to set off points *s*, *t*, *m*, *b*, *p*, at the same vertical height upon every rib, and drop perpendiculars from them upon the respective plan lines, intersecting the latter in R, *r*, *w*, *a*, *z*. Lines joining these points will give the desired form of the middle section. By drawing in this manner a series of equidistant horizontal sections from the impost to the

crown of the vault, the resulting lines upon the plan will form a species of shading that will show the exact nature of the entire form, much in the same manner as the topographical shading of mountains and broken ground in a survey is made to represent their exact solid figure upon the mere plan[26].

I have employed this system in sketching the plans of vaults, for by shading them in the intermediate compartments between the ribs with lines disposed according to this method as nearly as the eye will determine, the general disposition of the surfaces may be recorded with sufficient accuracy, and such a record is very desirable according to the views I have endeavoured to advance of the importance and effect of these dispositions upon the æsthetic character of the vault.

In conclusion, I must beg it to be recollected that I offer this paper as a sketch of an investigation, for the completion of which I request the assistance of the members of the Institute in the collection of facts and examples. I have endeavoured throughout to show from evidence the existence and employment of geometrical methods from a very early period, and have attempted to restore some of these methods. I have also ventured to assert the importance of certain forms and arrangements in imparting character to the buildings in question. The necessary limits of a paper of this kind have prevented me from introducing several topics which may appear to belong to the question in hand. Thus I have said nothing respecting mechanical principles, and have confined myself to form and arrangement. But it appears to me, from examination of

[26] If this method be followed out, it is capable of great precision. When the ribs are represented by single lines, the form of the entire group will be shown, as above. But the sections of the vaulting surfaces are often different from those of the group of ribs at the same level, and the sections of these surfaces may be obtained as follows. The ribs in the plan must be represented by parallel lines at the distance corresponding to the thickness of the rib, as in *fig.* 16 (p. 27), and not by single lines. The curves employed to obtain the middle plans must be the backs of the ribs, and not their front fillets. These, being the lines of junction between the vaulting surfaces and the ribs, are concentric to the front fillets for the most part. It is unnecessary to draw sections sufficiently close to shade the vault, as eight or ten between the crown and impost are sufficient to show the form of the vault, but in such a drawing care must be taken to note that these lines are not intended for joint lines.

The elevation of the curves must all be drawn with reference to a single base line, as in *fig.* 16, and not placed each on its own plan line, as in *fig.* 10. For thus a series of lines drawn parallel to the base G *k* (*fig.* 16) through all the ribs, will represent the parallel sections. A vertical line or axis upon the impost G will intersect all these, and the distance from this axis of the successive points of intersection of any given rib as it passes through the parallel sections in order, may be marked upon the edge of a slip of paper, and then transferred to the plan line of the rib in question. When this has been effected for each rib, the corresponding points must be joined, and thus the sections marked upon the plan. I find this process easy and rapid in practice, although I fear it will be scarcely intelligible without a figure. In *fig.* 15 (Plate I.) the left hand half is shaded upon this system, and the right hand half has parallel sections in dotted lines. These were sketched in, however, by eye merely.

the works of the Middle Age architects, that the latter considerations had an infinitely greater influence upon their structures than the relations of pressure, then very little understood, and about which they made manifest and sometimes fatal errors; so that this omission may be fairly allowed, or at least the discussion of this part of the subject may be carried on separately. Also with respect to the elaborate and beautiful class of vaults which I have termed Lierne Vaults, I propose, at some future time, to offer to the Institute a supplementary paper containing many observations upon them, and probably additional remarks upon the entire subject. Lastly, since the methods which I have explained in this paper have been for the most part elicited from an examination of the existing vaults, it may be worth while to compare them with those that are recommended and taught in the books of stone-cutting already quoted and referred to, as well as with modern actual practice.

Erratum.—Page 28, line 5 from bottom, for c m=3 ft. 6½ in. read c m=3 ft. 0½ in.

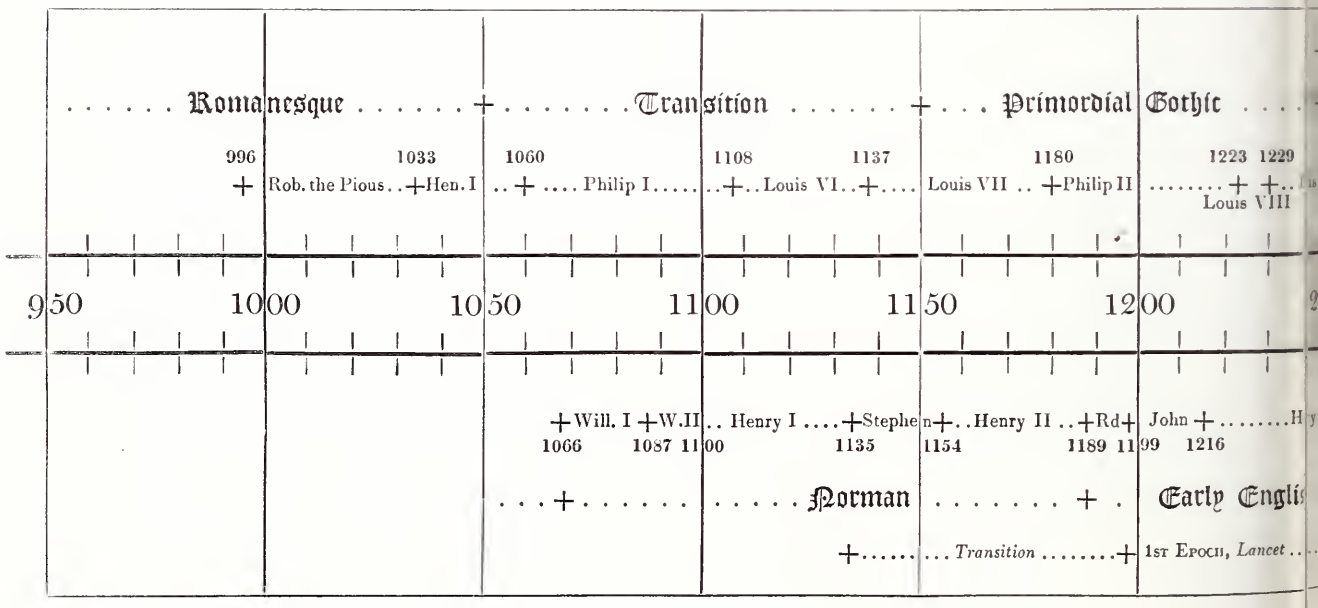
ON THE CONTEMPORARY STYLES OF GOTHIC ARCHITECTURE IN ENGLAND AND FRANCE.

By AMBROSE POYNTER, Fellow.

Read April 22, 1839.

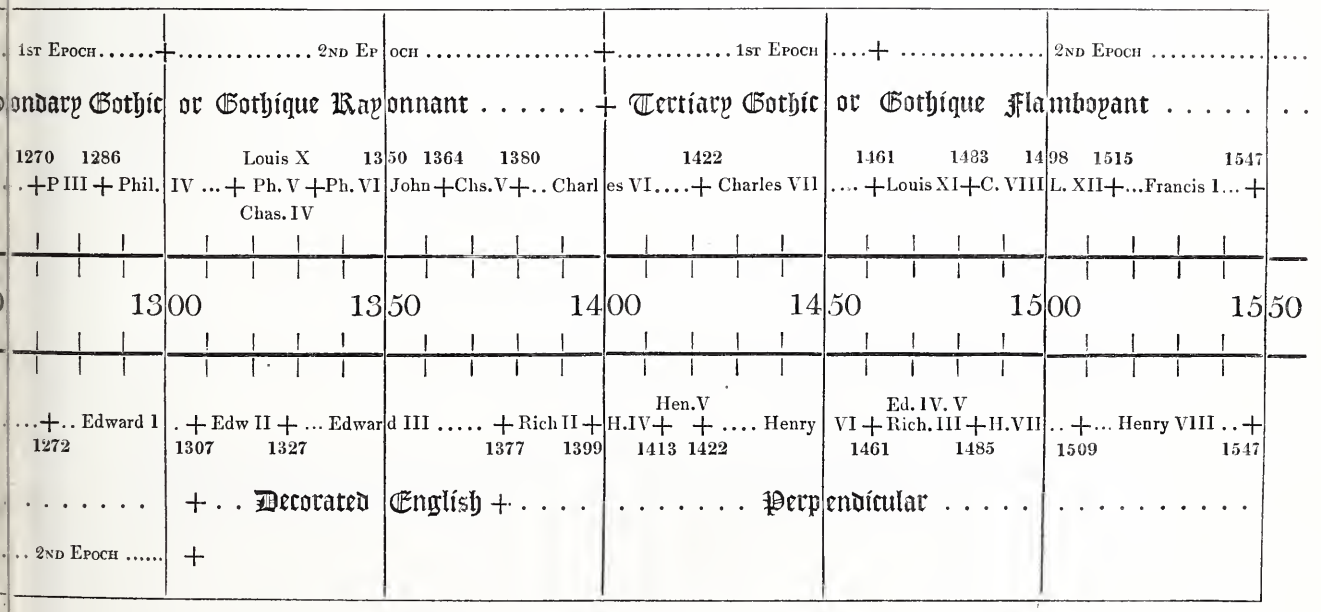
A SUPERFICIAL view of the progressive changes in English Architecture from the eleventh century to the fifteenth, is a subject so hackneyed, that it may be necessary to apologise for any dissertation so immediately bearing upon it as the annexed table may seem to promise. With the contents of one division of this table it is to be presumed every one interested in Gothic architecture is familiar, and its arrangement will at once explain the object of the present sketch.

The chronological division of the upper portion of the table is that laid



down by M. de Caumont, in a little work professedly written on the plan of some of the essays by English antiquaries. It is perhaps the only book on the subject worth mentioning, works of higher pretensions in the French language exhibiting a very general deficiency in the important requisites of facts and dates. The division and nomenclature of the lower part of the table are those of Rickman, with the addition of some subdivisions to assimilate it more nearly with that above.

That portion of M. de Caumont's arrangement which precedes our earliest architectural epoch will require but a short notice. There is doubtless a great deal of Romanesque architecture in France, of a much earlier date than any thing in England bearing the marks of a style, and retaining many features indicative of its immediate derivation from the Roman. There is a remarkable example engraved in Baron Taylor's work, of the Church of Poinset, bearing all the characteristics of the Norman Romanesque style, and decorated with the chevron ornament, and yet holding so far to the Roman that the aisles are roofed upon horizontal stone architraves. The Church of Ennery, near Pontoise, though not so remarkable in character, is extremely curious and interesting. The general style is that of the sixteenth century, obviously altered from a building in the earliest stage of the pointed arch; but the tower is Romanesque, and is found upon examination to have belonged to a much older structure, which has been worked into that now existing. The walls of this original church have been very low, with an immense roof resting upon a bold and



massive block cornice. There are no means of fixing a precise date upon this portion of the building, but it is certainly of great antiquity[1].

It will be observed that nearly the whole of our *Norman* period is marked in the French table as a period of transition from the Romanesque to the Gothic; but this term can by no means be accepted as implying the same thing as our transition to the Gothic; that is to say, from the style marked by the circular to that characterized by the pointed arch: it would throw back the introduction of the pointed arch to a date impossible to be maintained, though some French antiquaries have actually claimed for it this high antiquity. The transition here noted may, however, be taken as one from the Romanesque to the pointed style, through that modification of the former which we call Norman, and very properly so, since from the Normans we obtained it. In this sense the whole Norman period may be called a transition, since the fundamental principles of Gothic architecture may be developed, and were actually developed during this period, independently of any change in the form of the arch, which, though so thoroughly identified with the rise of Gothic architecture as to render it difficult to separate them, is in fact a mere accidental circumstance[2]. Whether this is M. de Caumont's view of the transition is not made quite clear.

The identity of the Norman and Anglo-Norman style is an historical as well as an architectural fact, and requires no argument to support it; and yet the Norman style seems to have been imported into England in scarcely so advanced a stage as that which it had attained in Normandy at the period of the Conquest. The three great Norman churches of Caen, St. Etienne, the Trinité, and St. Nicolas, exhibit an advance in the *transition* of which we shall find no examples in England until the twelfth century. On the other hand, there is a plainness, even to meanness, in the façades of some of the Norman churches, for which it is not easy to account. This remark applies particularly to the fronts of St. Etienne and the Abbey of Jumieges, which may be referred to in the works of Cotman and Pugin. The elaborate doorways of this style which abound in England even among insignificant country churches, form another difference between the Norman and Anglo-Norman architecture. These highly sculptured arches are not common in France. These discrepancies are more easily noticed than explained, since the buildings in both countries were equally the

[1] Some of these early churches are well illustrated in a recent work by M. Mallay, entitled "Essai sur les Eglises Romanes et Romano-Bysantines du Département du Puy de Dome," fol. Moulins, 1838.

[2] Mr. Rickman was the first to point out the essential principles of contrast between Roman and Gothic architecture, upon which some further observations will be found in Mr. Whewell's work on the German Churches.

works of Norman patrons and Norman architects, and sometimes it is probable of the same individuals. It has been suggested that, in pursuance of the system of the division of labour by which we know the works of the middle ages to have been produced, the details upon which these discrepancies arise may have been left in the hands of native artists, whom the Normans found established in England, and of whose services they availed themselves. It is certain that there is a marked distinction between the sculptural decorations of the opposite sides of the channel, the French very generally bearing the peculiar impress of Byzantine art, which is extremely rare in England. This country possessed, during the Anglo-Saxon period, a flourishing school of design as applied to the illumination of manuscripts[3], and it may not be too much to suppose that the art might have been extended to sculpture as well as to painting. This is merely an hypothesis, on the solution of a difficulty which arises in drawing a parallel between the Norman and Anglo-Norman styles of architecture.

From the circular to the pointed arch, the transition operated in Normandy in precisely the same manner as in England. Setting aside such pretensions as those to which reference has already been made, the Norman architecture seems to be some years in advance of ours in this respect; but the date assigned to the perfect Gothic church of Coutances (and supported by the Antiquarian Society of Normandy) of the first half of the eleventh century (palpably from the record of its rebuilding having been lost, while that of its original foundation has been preserved), though long maintained, is now given up by the more judicious French antiquaries. The cathedral of Séez also, which is an elegant Gothic structure, has been given to the period between 1053 and 1126. M. de Caumont, who is very candid on this point, admits that these dates are not generally allowed to the Gothic style, and is at a loss to reconcile them with the strong contradiction of internal evidence. The cathedral of Lisieux, again, it is impossible to assign to a date so early as from 1049 to 1077. Mr. Gally Knight has discussed the question of the antiquity of these three churches with great ability and success, in his Architectural Tour in Normandy. He shows, by documentary evidence, that the cathedral of Coutances was nearly ruined by Geoffry d'Harcourt in 1356, soon after the battle of Poitiers, the town of Séez taken and burnt (and therefore probably its cathedral) by Louis VII. in 1150, and again by the English in 1353, and the church of Lisieux burnt in 1136 and 1226. These facts at least show the great improbability of the existing buildings being the same as those referred to in the original accounts of their foundation. On the whole, there appears no reason to dissent

[3] Archæologia, vol. xxiv.

from the conclusion of M. de Caumont in assigning the middle of the twelfth century for the complete formation of the Primordial or Lancet Gothic; at the same time Mr. Rickman is undoubtedly right in his opinion that the Norman arch and details were used at a subsequent period, and in fact quite as late as in England, and M. de Caumont admits the same thing.

During the twelfth century, we find in England abundant examples of pointed arches with Norman mouldings, among other modes in which the transition operated, but we have no building of importance executed in this style, holding a place between the Norman and the Lancet Gothic, as in the greater part of the cathedral of Lisieux. The Trinity Chapel and Becket's crown at Canterbury come the nearest in style to this church, though there is a mixture of the circular arch in the one and a great deal of Norman decoration in the other, neither of which occur at Lisieux, at least in the interior; and it may be observed that in this cathedral occurs a specimen of the dog-tooth ornament, which is very rare in France, though so profusely introduced in our early Gothic. In the further developement of the perfect Gothic, the square abacus is the last remnant of the old style which is obliterated. It is found even in the nave of Coutances, but is superseded by the regular circular abacus in the eastern portion of the edifice.

This church has already been referred to as one of disputed date, but it is undoubtedly a work of the early part of the thirteenth century. It may be worth while to interrupt the thread of the chronology for a moment to describe it, since it has been seen by comparatively few English travellers, though one of the noblest specimens of its style of architecture in existence. The lantern surmounting the intersection of the cross, of the same date as the rest, is perfectly unique, and forcibly striking in its effect upon the interior view. This is not its only peculiarity. Like many of the great churches in France, the side aisles open upon an external range of chapels. These have been completed at a date somewhat later than the main building, the windows being large and open, and displaying the tracery of the *Gothique Rayonnant;* and the divisions between the chapels, instead of being walled up in the usual manner, are divided by open screens corresponding with the windows. The effect is the most scenic that can be imagined. The outside is no less remarkable than the interior, from the beautiful grouping of the lantern with the fine clustered spires at the west end, and the lofty pinnacles which surround the building on all sides.

The middle of the thirteenth century brings us to the Secondary Gothic, or *Gothique Rayonnant.*

If the Gothic style, taking the term in its general sense, was introduced later in England than in France, our Primordial or Lancet style seems no later in

A Poynter del. T.T Bury lith

EAST END OF COUTANCES CATHEDRAL.

Day & Haghe Lith.rs to the Queen

COUTANCES

making way for the Secondary Gothic. Some buildings there are of this latter style in France which also claim to be considerably in advance of any English examples, as the cathedral of Amiens, which was begun in the same year as that of Salisbury, 1221; but when we consider the alterations which invariably crept into Gothic buildings when they were long in progress, and that this church was not completed until the end of the thirteenth century or the beginning of the fourteenth, it need not disturb the general position that the first epoch of the Gothique Rayonnant corresponds pretty accurately, both in date and style, with the second of the Early English and the first of the Decorated English. The progression of style during the second half of the thirteenth century is much the same in France as in England, the windows expanding, their divisions increasing in number, and their tracery in complication. From the middle of the thirteenth to the middle of the fourteenth century is the most brilliant period of Gothic architecture in France, and a great number of the cathedrals and large churches were constructed and finished between these dates. One of the most perfect though not the most extensive examples of the first epoch of the Gothique Rayonnant, is the Sainte Chapelle at Paris, the work of Louis the Ninth. The stained glass is coeval with the building, of the most brilliant character, and perhaps the only specimen of the same era of an entire series of windows in a state of nearly perfect preservation. There are in this chapel fifteen windows, besides a *rosace*, or wheel window, over the entrance, of a later date. Eight of these windows are divided into four lights each; the other seven, which form the apsis, into two. The whole are laid out in compartments of varied and elegant patterns, formed in the iron work, each compartment (with the exception of those in one window which differs from the rest) containing a subject from scripture history, the number of figures varying from two to nine. Without reckoning a few which have perished, and some hidden behind certain bookcases with which the chapel was surrounded at its conversion into a record office, there remain nearly nine hundred of these compartments, for the most part in the highest state of preservation. The borders and back grounds are still more beautiful and brilliant than the compartments. This monument of the arts of the thirteenth century is certainly unique, and much less known than it deserves to be, though so much within reach. It must, however, be observed, that from its appropriation to a department of the Palais de Justice, there is no small difficulty in obtaining an entrance, or at least an opportunity to examine the glass, though perhaps not more than is usual in France with most objects of curiosity or interest, not always excepting even those which are professedly public shows[4].

[4] The Sainte Chapelle is at the present time in the hazardous predicament of undergoing *restoration*.

According to M. de Caumont, a second epoch of the Gothique Rayonnant extends throughout the fourteenth century. A considerable portion, however, of the latter part of this epoch is properly a transition to the Gothique Flamboyant; but there are no points of repose from which either the transition from the first to the second epoch of the Secondary Gothic, or from thence to the Tertiary Gothic, can be distinctly dated. The difficulty of marking the transitions will probably vanish when the French Gothic has been as diligently studied as our own; but it is certain that the mode in which they operate is by no means parallel in the two countries. The choir of Evreux Cathedral is indisputably a transition from the Gothique Rayonnant to the Gothique Flamboyant; but instead of acting upon the windows, which always exhibit early symptoms of change in English transitions, the alteration has principally affected the triforium, which exhibits a composition of pinnacles, curved pediments, and flowing lines, while the clerestory windows above are in the simplest style of the Gothique Rayonnant[5]. This example may be contrasted with Exeter Cathedral, where all the windows exhibit geometrical tracery, and many of them flowing lines, with a triforium marked with nothing of a corresponding character.

The tracery of the second epoch of the Gothique Rayonnant bears a considerable analogy to our geometrical tracery before the circle had been dismissed as the principal feature. A *rosace*, or foliated circle, generally forms the nucleus of decoration in the windows of the Gothique Rayonnant; and from this, as is well known, the style takes its name, as from the divergence of rays from the centre of a circle, the term Flamboyant referring to the long pointed *flame-like* divisions of the succeeding style.

The Norman Gothic touched its highest point about the middle of the fourteenth century, and the church of St. Ouen, at Rouen, may be considered as the most perfect type of the most perfect style of Gothic the world has seen. It needs no description, and no description, no pencil, could do justice to its elegance, its magnificence, and its purity. It is in the eastern portion of the edifice that the character of the Gothique Rayonnant is the most perfect; but though long in progress, the original design was always respected, and none of its progressive details have been suffered to injure the general effect.

After the first twenty years of the fourteenth century, we begin to lose all analogy between the styles of England and Normandy. Till that period some of our geometrical tracery, as already noticed, seems in a great degree parallel with that of the second epoch of the Gothique Rayonnant; but with this resemblance the parallel ceases, and the styles diverge to approach no more, with

[5] This triforium, like many others in France, is glazed with stained glass.

the introduction of flowing and ramified tracery, in which, from a comparison of known dates, this country appears to have rather the precedence. Our flowing tracery is not, however, the tracery either of the Gothique Rayonnant or the Gothique Flamboyant. We have few examples which resemble the later French tracery in any respect. The east window of Carlisle Cathedral is perhaps the nearest approach to it on a large scale.

With regard to the English style marked by flowing tracery, that is to say, the middle period of the Decorated English, when it was not in a state of actual transition, its title may be doubted to the distinction of being considered as a style at all. There has been a tendency to overrate the English architecture of this period, arising partly, perhaps, from its scarcity, and partly, it may be suspected, from looking less at what it really is than at what it might be, and judging of what it might be from the full developement of the contemporary style in other countries. It would perhaps be difficult to point out any building of importance in which any thing worthy to be called a style is fully developed in England during the short period in question. The western front of York Cathedral, occupying a place between the geometrical windows of the nave and the early Perpendicular of the choir, is one of our most considerable works in this style, and presents little that is satisfactory either in design or detail. The tracery of the great window is neither well composed nor well drawn, and an attempt at the pediments characteristic of the French Gothic over the side windows is altogether abortive. There is about the whole of this portion of the church a want of that completeness and consistency necessary to constitute a style, which is to be found in the Early English, the Gothique Rayonnant, the Gothique Flamboyant, and the Perpendicular; and this is so generally the case with English buildings of the same period, that it must be considered the rule, and not the exception. We also find our architecture of this period abounding in anomalies and caprices to a degree unknown in any other style laying claim to purity; as for example the invecked arch of one of the principal doorways of Redcliffe Church at Bristol, the whimsical composition of the windows at Dorchester, the aisle windows of the nave of Gloucester Cathedral, and the east window of Merton College Chapel. The flowing line is often overdone, and the disproportions in the members and details are sometimes startling, of both of which the late chapel of St. Stephen, at Westminster, the greatest boast of this epoch, furnished numerous instances.

The Gothique Flamboyant has already been described by Mr. Rickman in the 25th volume of the Archæologia[6]. Its leading features must be traced here

[6] Four letters on the Ecclesiastical Architecture of France.

for the purpose of contrasting it with our Perpendicular style. Like the Perpendicular, the depression of the arch is one of its characteristics; but the depressed arch of the Gothique Flamboyant is three-centred. This is sometimes, though rarely, found in England. The four-centred arch is so uncommon in France, that Mr. Rickman says he can find no distinct trace of it; but it may be seen in at least one place, the semi-Gothic church of St. Etienne du Mont, at Paris. The depressed arch does not enter into ecclesiastical architecture to the same extent in France as in England. It is for the most part confined to doorways and screen-work. Hence, in churches where the wall seems to be suppressed, and the building to consist of nothing but windows and buttresses, one of the characteristics of the Gothique Flamboyant, we frequently meet with windows, of which, in defiance of all grace and proportion, the head occupies two-thirds of the whole height. There is also a complicated but by no means ungraceful pediment, common in the Tertiary Gothic, and quite unknown in English architecture, of which an example is annexed, from the little church of St. Remi, near Dreux. Another characteristic of the Gothique Flamboyant is the continual crossing of the mouldings, and the complication of members, which seem multiplied for no other purpose but to be woven together in intricate combinations. These modes of decoration are very sparingly used in England[7]. The great fault of the Gothique Flamboyant as compared with the contemporary English style is, that it depends for its beauty mainly on the exuberance of its ornament. To its magnificent effects in its best days the churches of Rouen bear testimony, and it must be admitted that the utmost efforts of the English Perpendicular are dry and tame in comparison; but in its latter days the Gothique Flamboyant ran to seed, and fell into a state of degeneracy which English Gothic has escaped. It must, however, be observed, that in its worst days the tracery of the Gothique Flamboyant is beautifully drawn. One of the most gorgeous works of the Tertiary Gothic is the Tower of the Madelaine, at Verneuil, of which, as it is scarcely known in England, a representation is annexed[8]. The upper part is evidently the base of a spire, the

[7] "I must notice," says Mr. Rickman, "two very disagreeable piers which are not uncommon in this style. One is a series of eight hollows and eight rounds without fillets; this pier has a capital to each round, but it looks very poor and meagre for want of fillets. The other is a plain round pier with no capital, but the mouldings jumping out of the pier side, as if they had been soft and the pier stuck up into them. I know not that we have any thing like these in England." The first impression on meeting with the latter is, that it is of a much earlier date.

[8] Verneuil is a town full of interest. It contains several fine specimens of architecture, besides this magnificent tower, and some fortifications of the twelfth century in great preservation. Verneuil is in Normandy, on the high road from Paris to Brest.

A Poynter del. T.T. Bury lith

Day & Haghe lith.rs to the Queen.

DOOR of the CHURCH of St RÉMY.
near Dreux

discontinuance of which may be attributed to a subsidence of the foundation, which has caused the whole building to deviate slightly from the upright.

Having traced the parallel styles of the Gothic architecture of England with that of Normandy and the adjacent provinces, a few observations may be made in conclusion on some remarkable differences in the modes of composition adopted in the two countries.

In the Norman and Anglo-Norman churches there is no great variance either in the general plan or the mode of treating the elevation; but with the completion of the Gothic style important divarications occur in both respects. The general suppression of the apsis in English churches is one of the earliest and most considerable. In France the apsis maintained itself through every style, and in the greater churches differs from the English apsis in being usually divided into seven arches, which are necessarily of excessively tall and narrow proportions, and the columns supporting these arches are generally single shafts. Five aisles are not uncommon in French cathedrals. In England we have but one example, and that only partial, in the cathedral of Chichester. If there are but three aisles, the French cathedrals have an outer range of chapels, such as have been described at Coutances, of which there are only partial examples in England, as in the eastern part of Westminster Abbey. Sometimes this addition is made even to churches with five aisles, but this extension of breadth is apt to injure the external outline of the French churches, a defect noticed by Mr. Rickman. It is especially apparent in the apsides, as at Notre Dame, at Paris. In their west fronts the architects of the two countries appear to have taken exactly opposite courses in starting from the common point of the old Norman elevation, the English lowering their window till it reaches the door, the French raising their door till it reaches the window, which is commonly circular, as best adapted to the space it has to fill. Upon the portals, thus raised to the most important feature of the elevation, the French lavished their decoration with an unsparing hand; and it is sufficient to mention the results at Amiens, Chartres, Rheims, Rouen, Paris, Abbeville, and many others, embracing all styles and periods. In smaller churches it was the custom of the French architects to make the portal occupy the whole height of the centre compartment: an arrangement which, producing an excellent effect from its simplicity, may reprove a practice too common in modern Gothic architecture, of executing great designs on a small scale, and little designs on a large one. The church of St. Remi, already noticed, affords an example. The wheel windows are no less the glory of French Gothic. We have but few specimens in this country: of the Early English, a very fine one at York; at

Lincoln, of the Decorated English, ill drawn and confused, as is common with the tracery of that period; and of the Perpendicular at Westminster, replacing originals of an earlier date. A few of less note may be found in parish churches, as for example at Cheltenham. The spires of Normandy are curious from their similarity to each other, though of different epochs. The spires of St. Lo and Coutances, of St. Etienne at Caen, of St. Pierre and St. Sauveur in the same city, of Bayeux Cathedral, and of the beautiful church of Carentan, embracing all dates and styles, are much alike, and the last five are essentially the same design, with little modification besides the progression of the detail. They are all composed with clustered pinnacles and cut on the face in bands; and several of them agree in a series of apertures, beginning with a circle of several foliations at the bottom, and gradually diminishing to a trefoil near the top, as the spire contracts. The pediments which surmount the windows, and form an apex to each separate bay of the building, form another peculiarity in the French ecclesiastical Gothic. The Sainte Chapelle furnishes an early and simple example. In the Gothique Flamboyant these pediments mount high above the parapets, and are worked open with the delicacy and richness of lace. In vaulting, the English Gothic has a decided advantage. The French have little to compare with our highly decorated vaults of the fifteenth century, and still less anything resembling fan tracery. Their roofs, as long as the Gothic style remained pure, seldom advance beyond the simplest elements of ribbed vaulting. This arises from no ignorance of the effects of enriched vaulting, since there are beautiful groins with pendants in some of the Norman porches. Mr. Rickman attributes this poverty in the vaulting to the vast elevation of the French churches, supposing that at so great a height an ornamental style of groining would be lost; but the fact is, that the spandrels were left plain for the purpose of painting on them, though it is seldom this design has been carried into effect. One of the very few examples of complication in the vaulting as long as the Gothic style remains unmixed, occurs in the chancel of the little church of Nonancourt, near Dreux. The last peculiarity to be noticed is, that battlements are never to be seen in ecclesiastical buildings in France. Open parapets are universal in the later styles.

I am quite aware of the slight texture of the foregoing observations, but they refer to a subject which has hitherto been little investigated, and may serve as an index to more diligent inquiries.

ON THE CHARACTERISTIC INTERPENETRATIONS OF THE FLAMBOYANT STYLE.

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AMONGST other characters that distinguish the later styles of Gothic on the continent from our own contemporary Perpendicular style, there may be observed a much greater and more fanciful intricacy of parts, contrived apparently more with a view to display difficulties overcome than beauties of art. Hence an excessive employment of interpenetrating surfaces, especially in the Flamboyant Style. In English examples a moulding may sometimes be found which penetrates some projecting member, and appears on the other side, as for example in *fig.* 1, which represents a portion of the base of one of the turrets of King's College Chapel. The string moulding at A A appears on the face of the plinths of the angle buttresses as if it had penetrated their substance, or rather the whole arrangement of the bases of the turrets and of the buttresses respectively, appears to suggest a mutual penetration or *interpenetration* of the two. Examples of this kind are not common in English work, and are confined merely to the interferences of adjacent necessary members of the architectural arrangement.

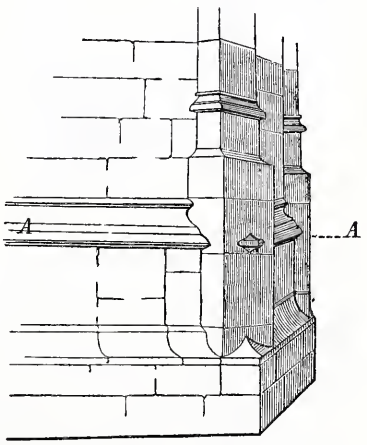


Fig. 1.

In the Flamboyant style, on the contrary, interpenetration occurs so frequently as to constitute a characteristic, and is produced not merely between two neighbouring architectural members, but new members are also introduced for the mere purpose of showing interpenetrations. Thus, as we shall see, two different bases may be given to the same shaft, or even two or more different turrets with pinnacles may be placed in an identical

position on the plan, and made to interfere and interpenetrate throughout their entire height from the base upwards in a manner that defies description, and can only be illustrated by drawings.

It may perhaps be found that this character only belongs to one period or one district of the Flamboyant style; my opportunities of observing examples have been scarcely sufficient to enable me to decide this point; but my present object is to explain and define a practice which I know to be sufficiently extensive to constitute a distinguishing characteristic, and not to be merely an individual caprice. The few examples that I am going to produce must be looked upon as specimens of an entire class of similar ones.

The bottom of a spiral staircase in the Palace at Nevers (*fig.* 2) exhibits two

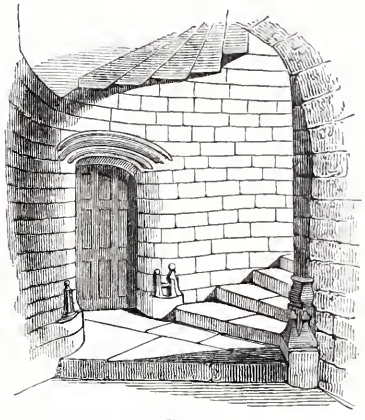


Fig. 2.

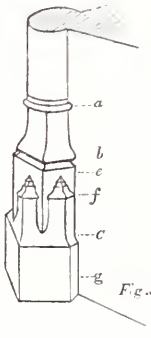


Fig. 3.

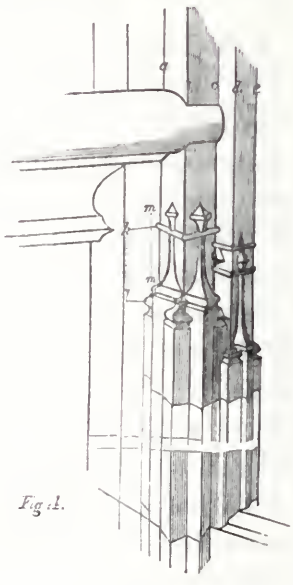


Fig. 4.

characteristic specimens of interpenetration; in the doorway and in the base of the column which forms the newel of the stairs. This column (vide *fig.* 3) is furnished with the usual base mouldings, *a*, *b*, and polygonal plinth, *b*, *c*, but in addition to this another complete base with mouldings and polygonal plinth, *e*, *f*, *g*, is added below, and made to show interpenetrations by having its faces set opposite to the angles of the upper base.

Fig. 4 is a sketch of base mouldings from a rich screen in the cathedral at Chartres, which separates the choir from its side aisles. The forms to which the bases are applied consist of rectangular projections, *a b c*, *c d e*. The first of these has a base with the usual mouldings, *k*, *l*, and also an interpenetrating base of a similar profile, *m*, *m*, but set anglewise, and not as in the last example

completely below the first base, but arranged with its mouldings each a little above the corresponding moulding of the first base *k*, *l*, in order to display the interpenetration more completely. The neighbouring projection *c*, *d*, *e*, has a pair of bases of the same kind, but carefully managed so as to avoid any appearance of continuity or connexion with either base of the projection *a*, *b*, *c*, and thus to increase the complication of effect.

Fig. 5 is an example from the same screen, but showing perhaps still more ingenuity in the production of complicated interferences. The member to which this base is applied is a plain prism terminating upwards in a pinnacle; its form appears from the *plan* in the margin, which shows its horizontal section immediately above the base.

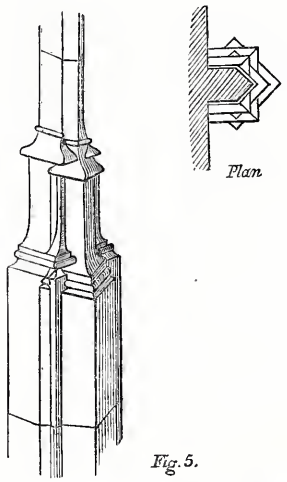


Fig. 5.

Instead of mitring the base mouldings round this prism, which would be the natural arrangement for a single architectural member, the base is applied on the supposition that this prism consists of two interpenetrating square prisms, one of which is set anglewise with respect to the other, and the base mouldings of the latter are placed a little lower down than those of the former, so as to produce the interpenetrations which are clearly shown in the drawing.

This prism has a few usual mouldings added to it near the upper extremity by way of capital below the pinnacle. These, which I have not shown in the drawing, are treated precisely in the same manner as the base mouldings.

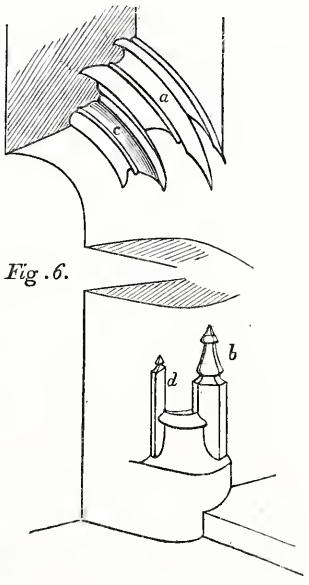


Fig. 6.

To return to the doorway, *fig.* 2, of which the mouldings and base are shown on a larger scale at *fig.* 6. The mouldings of this doorway are made to die against the vertical surface of the piers in a manner very usual in Gothic architecture, and to which I have ventured elsewhere to assign the name of a discontinuous impost. So far this doorway presents nothing different from many others in the contemporaneous or previous styles. At the base of the piers, however, some architectural ornaments are shown, which constitute the peculiar Flamboyant character to which I wish to

direct attention. These ornaments, marked *b* and *d* (*fig.* 6), upon examination resolve themselves into prominent edges of the regular bases of the arch mouldings *a* and *c* (*fig.* 6), which interpenetrate the pier, and so show themselves, together with the requisite portion of the plinth mouldings.

To make this more intelligible, I have drawn in *fig.* 7, on the same scale and from the same point of view, the complete base that would have been given to these arch mouldings, supposing them to have been continued down the sides of the pier, the arch having a *continuous impost*.

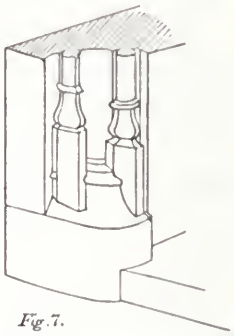


Fig. 7.

In simple Flamboyant examples such a base would have been employed, and indeed one very similar may be seen on the same staircase applied to the mouldings of the window sides. This figure compared with *fig.* 6 will explain the forms which the bases *d* and *b* assume by piercing the surface of the plain rounded pier with which they interpenetrate, and in whose substance they are thus supposed to exist with the entire set of mouldings.

In many Flamboyant examples small knobs and projections like *b* and *d* (*fig.* 6) may be observed, and on a superficial view might pass for mere unmeaning ornaments, but will be found explicable upon this system of interpenetration. *Fig.* 8 is a window (from a house near Roanne), at the base of whose mullions knobs may be observed, which really represent the Gothic base of a square mullion on the same plinth with the hollow chamfered mullion, and interpenetrating with it. *Fig.* 9 is the base of a mullion from a house at Vienne, somewhat more complex, but intelligible on a similar supposition.

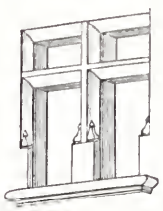


Fig. 8.

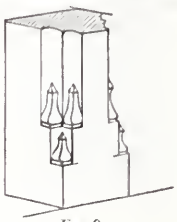


Fig. 9.

Fig. 10 is an example of a class of interpenetration still bolder than any we have hitherto examined, and in which two or more complete architectural members are supposed to coexist in the same spot and to interpenetrate throughout their entire height.

This example is a rich doorway in the north transept of the cathedral at Nevers, leading to one of those fanciful and characteristic spiral staircases which frequently occur in the Flamboyant churches. The composition is similar to that of Gothic doorways in general, consisting of an archway decorated with rich continuous mouldings and a transom of the Flamboyant form, over which is a group of sculpture, not represented in the sketch. The archway is sur-

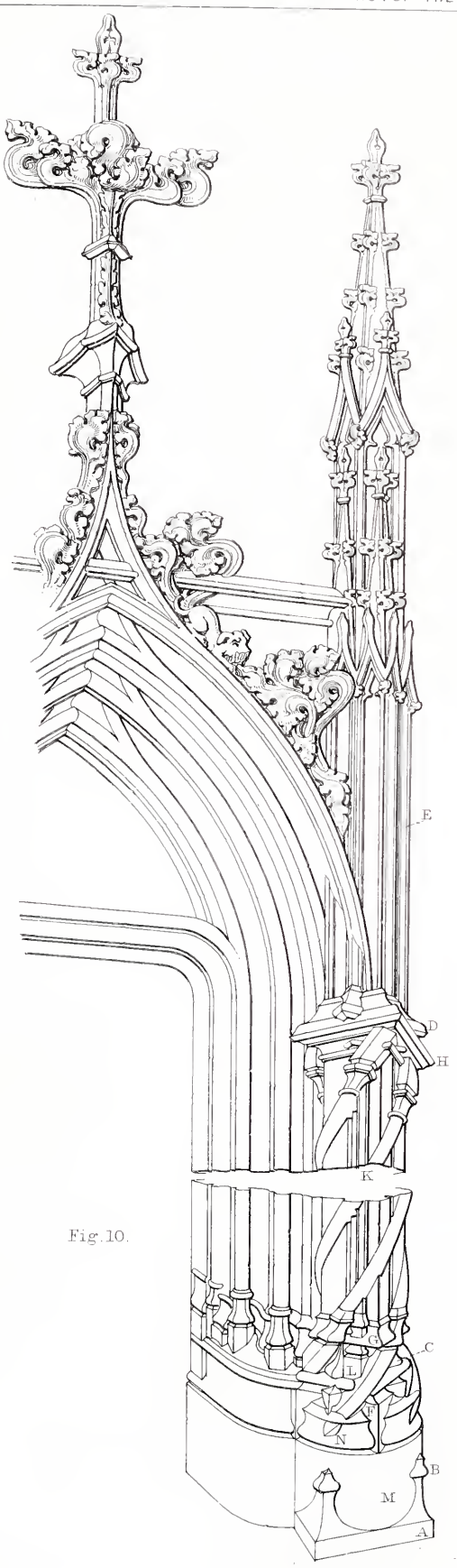


Fig. 10.

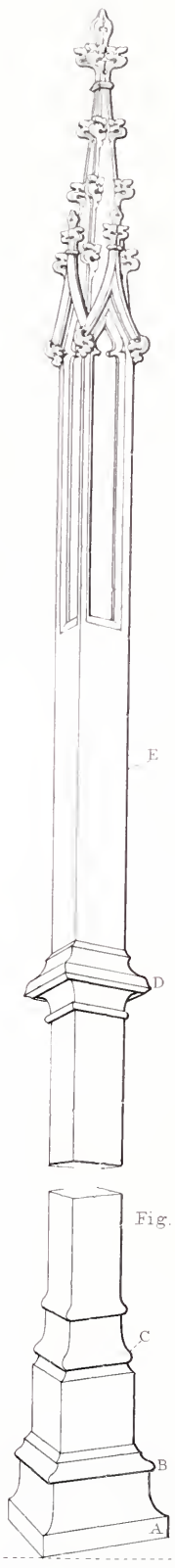


Fig. 11.

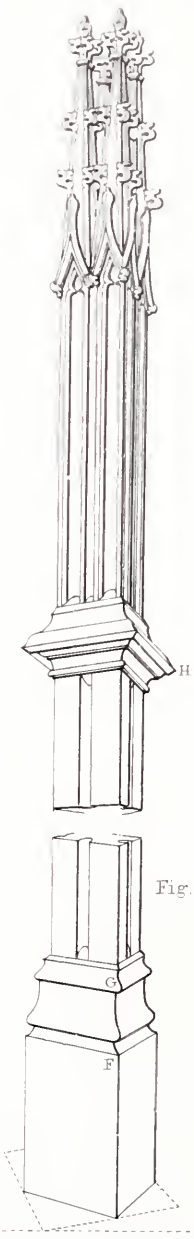


Fig. 12.

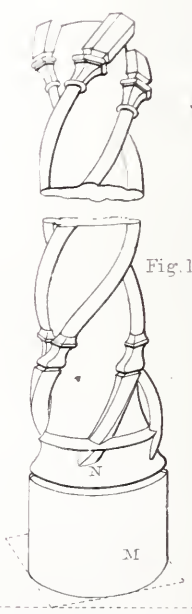


Fig. 13.

R. Willis. del.

T. T. Bury. sc.

DOORWAY IN THE CATHEDRAL OF NEVERS.

mounted by an ogee canopy, with large crockets, and animals, and a spreading finial; and the whole is flanked by piles of pinnacles, to which I must direct particular attention as containing the interpenetrations in question.

The pier of the doorway is considerably higher than in the drawing, but as it was necessary to show the interpenetrations on a large scale, the pier is represented as fractured in the middle, and a portion containing one entire turn of the spiral column is omitted. I must also remark that the details of the foliage and crocketing of the upper part are not very accurately represented, as for want of time a very hasty sketch of these parts was taken; but that the interpenetrating mouldings are drawn with sufficient care and precision.

The vertical piers with pinnacles which flank the composition, one only of which is shown in the sketch, present at the base and impost a confused knot of architectural details, interlacing and interpenetrating each other in every possible manner. An accurate examination shows that this complication is produced by the co-existence upon the plan of three distinct architectural members, each having its own set of mouldings.

I have drawn these separately in *figs.* 11, 12, and 13, on the same scale and from the same point of view as in the group; and by comparing them singly with *fig.* 10, by help of the corresponding letters of reference, the mystery of its complication will be easily unravelled.

The first (*fig.* 11) is a square shaft or pedestal with base and cap mouldings, surmounted by a square pannelled shaft terminated upwards by a pinnacle of the usual form with gables, crockets, and a finial. The plinth of this shaft exhibits itself at the bottom of the pier at A; its base mouldings may be detected by their angles, as at B and C. The mouldings of the cap also show their corners, as at D. The vertical edges of the pedestal are prominent between the spiral shafts, and the vertical edges of the upper shaft are also shown, as at E, while the pinnacle rises clear and detached above the whole.

The second member (*fig.* 12) is also a square pedestal with base and cap mouldings; but it is set lozengewise with respect to the wall, so that its angles fall opposite the faces of the former one. Its mouldings are somewhat different, and carefully placed at a different level. Its shaft being divided or split into four, allows the edges of the first one to exhibit themselves more clearly; and above its cap it carries a group of four separate shafts pannelled and surmounted each by a pinnacle with gables, crockets, and finials complete. The upper part of its square plinth and the greater portion in length of its base mouldings show themselves, as at F and G. The faces of its square shaft are also visible, and the mouldings of the cap, the entire prominent edge of which

is seen at n, as well as the outer faces of the panelled pinnacle shafts above. The pinnacles themselves are of course half absorbed in the square shaft, which rises through them, and against which they appear to be applied.

The third member of this intricate mass is the group of twisted shafts (*fig.* 13). This rises no higher than the caps of the former pedestals. It consists of a cylindrical or spiral column with a cylindrical plinth and base mouldings, round which are twisted four slender shafts, each having its own plinth, base, and capital complete, the plinths interpenetrating with the base moulding of the cylindrical column. The place of this in the general mass is so clearly shown in *fig.* 10, as scarcely to require letters of reference, m and n, which, however, show two corresponding points.

But in addition to these three principal parts, *figs.* 11, 12, and 13, it will be observed that the fillet of the dripstone of the canopy is continued downwards upon the face of the pier at k, and is provided with a small separate base and plinth at l, which base interpenetrates the upper base moulding of *fig.* 12.

As other instances of the same principle may be remarked the manner in which the ogee mouldings are given to every one of the arch-head mouldings, as well as the interpenetration of the horizontal string at m with the ogee head. But such simple cases as these may be seen in English or German examples. Also small pinnacles may be found in all the Gothic styles applied lozengewise against the shafts of large ones. But they are always so disposed as to appear as if they were so applied, and not as portions of one entire composition standing upon the same plan as the central one, as in this and other Flamboyant specimens.

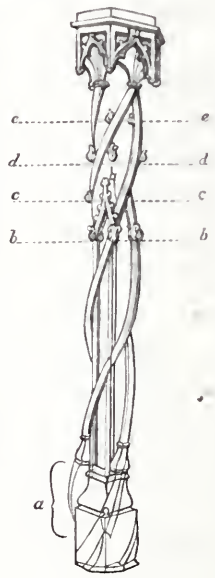


Fig. 14.

As another example we may take *fig.* 14, "le piédestal de S. Clotilde," in Evreux Cathedral. This consists of two entire members, interpenetrating from the base to the top of the whole.

One of these is a spiral column somewhat similar to *fig.* 13, but in this case consisting of three shafts only, which terminate upwards with great elegance, supporting the branching ribs of small vaults which carry an hexagonal crown, forming the table of the pedestal.

The other member is an ordinary square shaft with pannelled sides, base mouldings, and plinth at *a*, with gables crockets and finial of the usual form at *b*, *b*, surmounted by a pinnacle with crockets and finial. These crockets may be seen at *c c*, *d d*, *e e*, but since from

the pyramidal form of the pinnacle they retire inwards as they rise in succession, they are in the original carefully and accurately represented as gradually absorbed in the substance of the spiral column; the upper crockets and finial are of course entirely concealed and buried in it.

In Germany and in the Low Countries the later styles of Gothic are worked with a profusion of interpenetrating and interlacing mouldings, but these are always confined to the interferences that can be produced between the details of neighbouring architectural members, and are therefore to be considered as belonging to the same class as the similar examples that occasionally occur in English work, but as carried to a greater excess; and indeed the Flamboyant specimens abound with this kind of enrichment, in addition to the peculiar kind of it which this essay is intended to point out.

The distinguishing characteristic of the Flamboyant interpenetration will now, I hope, have been made clearer by the examples explained in the drawings, namely, that the interferences are produced not merely between neighbouring architectural members, but by placing two coexisting members of the same kind in the same place, and by making their forms or their relative position different, so to produce the desired intricacy of effect.

Thus *figs.* 3, 4, 5, 8, and 9, are examples of two co-existing bases; and in the doorway of *fig.* 2 we have two co-existing piers on each side of a single arch; for since the base of the pier has been shown to be that which belongs not to the actual pier but to the one that is supposed to interpenetrate with it, the co-existence of this last with the actual one is immediately suggested when the artifice is explained.

In the two last examples, *figs.* 10 and 14, this principle of co-existence is carried out much more completely by extending it from parts to wholes.

Having thus shown that the cases I have selected have a common principle, and one which is characteristic of local practice, I trust that a sufficient apology is offered for the length at which I have thought it necessary to explain and examine them.

July 2, 1840.

HISTORY OF GRECO-RUSSIAN ECCLESIASTICAL ARCHITECTURE.

By HERR HALLMANN, Architect, from Hanover.

Read at the Ordinary Meeting, held Monday, the 20th of January, 1840.

THE MEDAL OF THE INSTITUTE WAS AWARDED TO HERR HALLMANN FOR THIS PAPER.

BEFORE examining the existing Russian churches it will be necessary and may prove interesting to take a hasty glance at the origin and history of Christianity in Russia, as connected with the edifices dedicated to the service of religion. We shall see that the Russian churches[1], like an old tradition, have remained nearly the same for many ages.

One of the first Christians in Russia was the Princess Olga, who caused herself to be baptized at Constantinople in the year 964. But the era of the general profession of Christianity did not commence till the reign of Vladimir the Great (981—1015). The first church, that this sovereign caused to be built, was that of Cherson (988); and a year afterwards he ordered the construction of the church of St. Basil. Both were of wood. He also sent embassies into Italy and Arabia and to Constantinople, to inquire into the state of religion; for the western and eastern churches were already separated. The ambassadors were astonished at the splendor and magnificence with which divine service was celebrated in the church of St. Sophia at Constantinople; and Prince Vladimir, according to their report, embracing the Greek religion, ordered the baptism of the whole of his people, and was the first to commence the destruction of the ancient idols. There exists a tradition belonging to those times too original to be omitted. The principal idol Peroun the god of thunder, whose image was a wooden statue having a silver head with golden mustachios, had a sanctuary at Novgorod. It is related, that, upon the statue being precipitated

[1] Mr. Hope's Historical Essay on Architecture contains much useful information in connexion with the subject of this paper.

into the river, the idol rose from the waves, and casting a thick stick upon the shore exclaimed "Behold citizens what I bequeath you as a remembrance." Although Christianity prevailed, it appears that the inheritance of paganism was still respected; for the stick is the object of a peculiar worship in Russia down to the present time.

Vladimir built the church of the Tithe at Kieff (996—1007), and brought many of the Greek images to that city; and it is said, that at the time of his death there were already four hundred churches at Kieff.

1019—1054. Prince Yaroslaf turned his attention still more than Vladimir to the construction of religious edifices. He founded the church of St. Sophia at Kieff, and another of the same name at Novgorod; and according to the chronicle they were executed by Greek artists; portions of these buildings still exist. The churches were covered in the interior with gold and mosaics, and there are some remains of these ornaments even at the present day. He also erected the convents of St. George and St. Irene. The sarcophagus of Yaroslaf is still in the church of St. Sophia at Kieff; it is of a blueish white marble and its ornaments are composed of birds and foliage, similar to some at Ravenna. In his reign divine service was first chaunted or sung. The ambassadors of the Emperor Henry IV. of Germany dealt in fabulous accounts of the magnificence of the city of Kieff and of the riches of the treasury.

In 1075 was built the celebrated convent of Petchersky at Kieff, from which time the Russian metropolitans became subordinate to the metropolitans of Constantinople; and in 1089 mention is made for the first time of a baptistry apart from the church; this was under the metropolitan Ephraim in the city of Pereaslaw-Saleski. Christianity made rapid progress in these countries, but it would be superfluous to attempt the mention of all the churches and convents, which were erected during that age throughout the empire—the most remarkable were the convent of Volkof (1100) and of Yourief at Novgorod, the church of the Ascension at Kieff, and especially the superb church in the city of Vladimir (1046) likewise built by Greek artists; much has been said of its many vases of massive gold, its golden doors, its paintings brilliant with precious stones, and its balustrades of silver. There existed an uninterrupted communication between Constantinople and Kieff; various marriages between the reigning houses of the two countries were celebrated; many Russians went to Jerusalem (1116—1125) under the Emperor Alexis Comnenus, and in the treasury of the Kremlin there are supposed to be the relics of the crown of those times (the cap of monomaque).

1124. But now begin the disasters of Kieff. A great fire destroyed six hundred churches and monasteries. Kieff was taken in the civil war under Yisaslaf; it was set on fire and mercilessly ravaged, the churches were plundered, the images thrown down and mutilated, and finally (1204), nearly at the same time that Constantinople was taken by the Venetians, the city of Kieff was ravaged and destroyed a second time, never to regain its former splendor!

As Kieff was modelled upon Constantinople, so Moscow, of a more recent origin, was likely to bear much resemblance to Kieff. Moscow is first mentioned in the year 1154, and at that time it was but a miserable village. Daniel of Moscow added to it greatly; and in the year 1304 under John Danielowitch the city was chosen capital of the empire; where on the 4th of August 1326 was laid the first stone of the church of the Assumption of the Virgin in the Kremlin, and the people of Iver were obliged to bring their great bell to Moscow (1330).

1328—1340. John Calita built the church of St. Michael the Archangel in the Kremlin, where repose the remains of the whole imperial dynasty. He founded also the church of St. John Calimagne and that of the Transfiguration 1339. The church of the Assumption is known to have been painted by Greeks and the church of St. Michael by the painters of the court, named Zacharia Joseph and Nicholas. A Russian of the name of Boris was at that time celebrated as the founder of the bells of Moscow and Novgorod.

1340—1353. At this time likewise was built the richest and most celebrated of all the convents in Russia, that of the Trinity near Moscow, under Simon the Proud (1367). The palace of the Kremlin, until then of wood, was erected in stone under Dimitri Donskoi.

We are now entering upon an age in which Russia became a prey to misfortune and disasters, namely the epoch of the great invasion of the Tartars. They burnt nearly the whole city of Moscow; plague famine and war combined to ruin the empire. Little mention is made of new churches during that period, but three painters known at Moscow (1408) are noticed under the denominations of *Simon the Black*, Prokhar, and Daniel of Gorodez.

1425—1462. Under the reign of Vassili the Blind, and after the taking of Constantinople by Mahomet II. the church of Russia ceased to be dependent upon that city.

1462—1505. With the reign of Ivan III. begins a new era of art in Russia, and a great part of the antiquities at Moscow date from this epoch. He caused the church of the Assumption in the Kremlin to be restored, but before its

consecration the new church fell in. The prince, vexed at the circumstance, sent an embassy into Germany and Italy to procure skilful artists; and an architect named Aristote, a native of Bologna, and celebrated at the time at Venice, constructed in Moscow the church of the Assumption upon the former plan, and as it exists at the present day. He decided, from a careful examination of the materials at his command, upon constructing the vaults of hewn stone, previous to making a journey to Vladimir, the ancient church of which is said to have excited his admiration. In the year 1479 the new cathedral of Moscow was consecrated. Another architect, named Pietro Antonio, built in 1487 a palace known by the name of the Granite Palace in the Kremlin; and a third Italian Alevigo constructed in brick a palace called the Belvidere. About the same time (1499) Paul de Bossio, Pietro, and the architect Aristote, cast the gigantic cannons still to be seen before the arsenal in the Kremlin. Having perhaps greater liberty in the construction of the palaces than in that of the churches, the influence of Italian taste of these architects is very evident; their style is a singular mixture of the Florentine, Venetian and Eastern. The ground floor is nearly without windows, and constructed with large hewn stone in the manner of the palaces of Florence: on the first floor the windows are of considerable width, and divided into two parts by a slender column in the middle. The effect is good and would be finer and more venerable if the whole were not miserably whitened.

1505—1534. In the reign of Vassili Ivanowitch Alevize the younger rebuilt the church of St. Michael, and the prince himself replaced there the coffins of his ancestors; the church of the Assumption was also repainted 1515 by Feodor Edikof, and contemporary spectators were so delighted with it as to say "We behold the open heavens." Different times, different tastes! The skies of the ancient Russians must have been singularly deficient in beauty and we may almost interpret literally the remarkable inscription, taken from the Holy Scriptures, round a gigantic head of Christ in the church of Novgorod "Behold what a terrible God, is your God!"

1534—1584. Ivan IV. the Cruel did much for the arts; he sent an embassy into Germany under the direction of Schlit who collected one hundred and fifty different artists: but he never reached Russia, being detained at Lubec from motives of jealousy. He likewise renewed the laws for exactly imitating the ancient painting in new churches. Hence the reason why all the paintings of the Greek church are so much alike, that it is impossible to judge of their epoch; but they may be regarded as the type of the earliest Christianity. Ivan

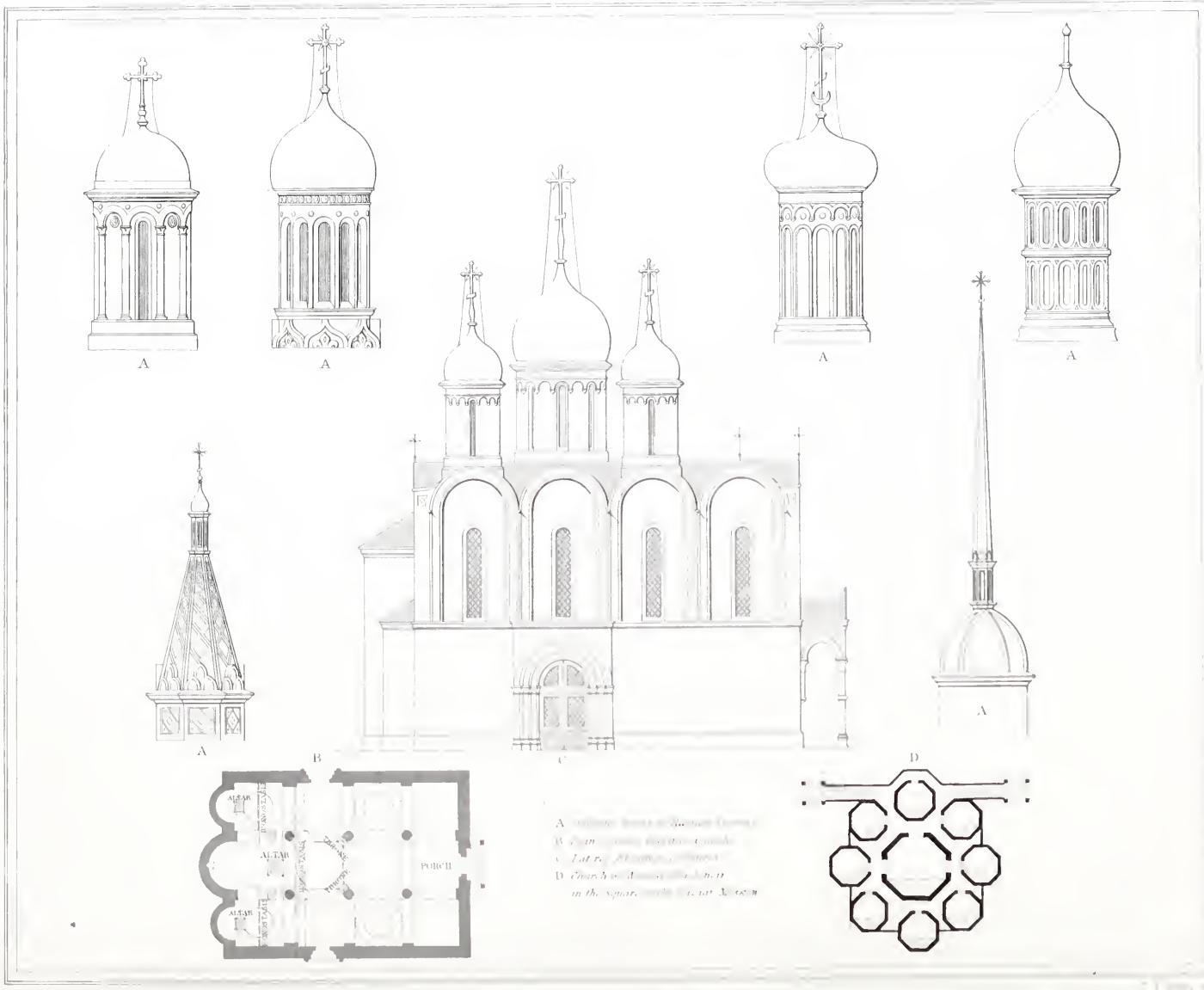
built the church of St. Basil, one of the most fantastic edifices imaginable, and also the only one of which the plan and interior and exterior decoration differ greatly from the other churches. The architect was likewise a foreigner, and Ivan ordered him "to employ the best resources of his art." When finished Ivan was satisfied with it, and on rewarding the architect asked if there were any possibility of his building a finer edifice;—the unfortunate artist, proud of his art, replied in the affirmative, and the tyrant caused him to be blinded and murdered in a miserable manner.

1584—1598. During the reign of Feodor, mention is for the first time made of other pictures besides the mere effigies of the saints. In the granite palace at the Kremlin was seen at that time a picture representing "the division of the empire between the sons of Vladimir the Great" and some, the subjects of which were taken from sacred history.

1600. The Czar Boris caused the erection of the magnificent clock tower Ivan-Veliki at the Kremlin. At this period Moscow could reckon four hundred churches, thirty-five of which were at the Kremlin alone. It still remains to speak of all, that has been constructed since that age down to the present day; but all these buildings present so few remarkable features, either with respect to the history of the church or to art itself, that it is unnecessary to notice them particularly.

1682—1725. From the time of Peter the Great, and particularly at Petersburgh, a change of style took place, and the type of the ancient church was replaced by a foreign style. If the developement of art in Russia was retarded in consequence of the strict imitation of ancient forms, it was still more so by the employment of forms by no means properly understood; but of this there will be occasion to speak by-and-by.

After this general view of the progress of Christian art in the empire of Russia, let us now turn our attention to the consideration of the Russian church itself, and for this purpose let us examine the cathedral church of the Assumption of the Virgin at Moscow, as holding the middle rank amongst existing churches, both as to its form and time of construction (1326). This examination will allow of an opportunity to cite the striking differences, where there be such, in other churches, and finally I shall endeavour to draw a parallel between the Russian church and that of the East in general, and of those countries, where oriental influence is visible.



A Hallmann del.

THE PRINCIPAL FEATURES OF A GRECO-RUSSIAN CHURCH

On the Plan, Arrangement, and Decoration of a Greco-Russian Church.

Sect. 1.—*The Plan.*

The plan of the church forms an oblong square divided, the arched ceiling being supported by six columns at equal distances in the interior. Upon a first glance the form of the Greek cross is not apparent; but it is indicated by the arrangement of the cupolas. The more ancient churches often form an exact square preceded by a porch; but here the porch is united with the interior of the church, and the arches and cupolas are placed, as if the church still retained the primitive form. The six columns divide the church into four parts from east to west, and in three from north to south. On the eastern side are seen three apsides only divided by the width of a pillar. The apsides form in the interior a complete semicircle, but on the exterior there appear but segments on account of the thickness of the principal wall. The middle apsis is more spacious than the side ones; this arrangement is found in nearly all the Greek churches, and these apsides indicate the situation of three altars, which occur everywhere, except in small chapels. The three altars are not visible to the public—they are covered or concealed by the Iconostasis, an arrangement indispensable in the Greek church. This Iconostasis[2] (or image bearer) is merely a kind of colossal skreen, generally attached to the first columns towards the east, occupying the whole width of the church, and rising up to the vaulting, thus dividing the church into two separate parts. The Iconostasis has three doors; a principal one in the middle and a smaller one on each side; behind the Iconostasis in the middle is placed the altar. This grand altar is surmounted by a baldaquin supported by four columns, and composed of a cupola or canopy; the altar corresponds with the great apsis as in the Latin churches.

Behind the lateral doors there is another distribution. On each side stands a second Iconostasis occupying only the width of the smaller apsis, the arrangement of which with three doors and an altar behind is analogous to the great one. This is met with in the ancient churches; in the more modern an alteration

[2] There are some beautiful views of Iconostases in Greek churches in the elegant work on Constantinople from drawings by our associate, Mr. Thomas Allom, published by Fisher and Co. The altar skreen in many of our cathedrals and large churches of the Roman Catholic times, as at Gloucester, St. Albans, and St. Saviour's, Southwark, is a corresponding feature to the Greek Iconostasis—borrowed perhaps by the Latin from the Greek church.

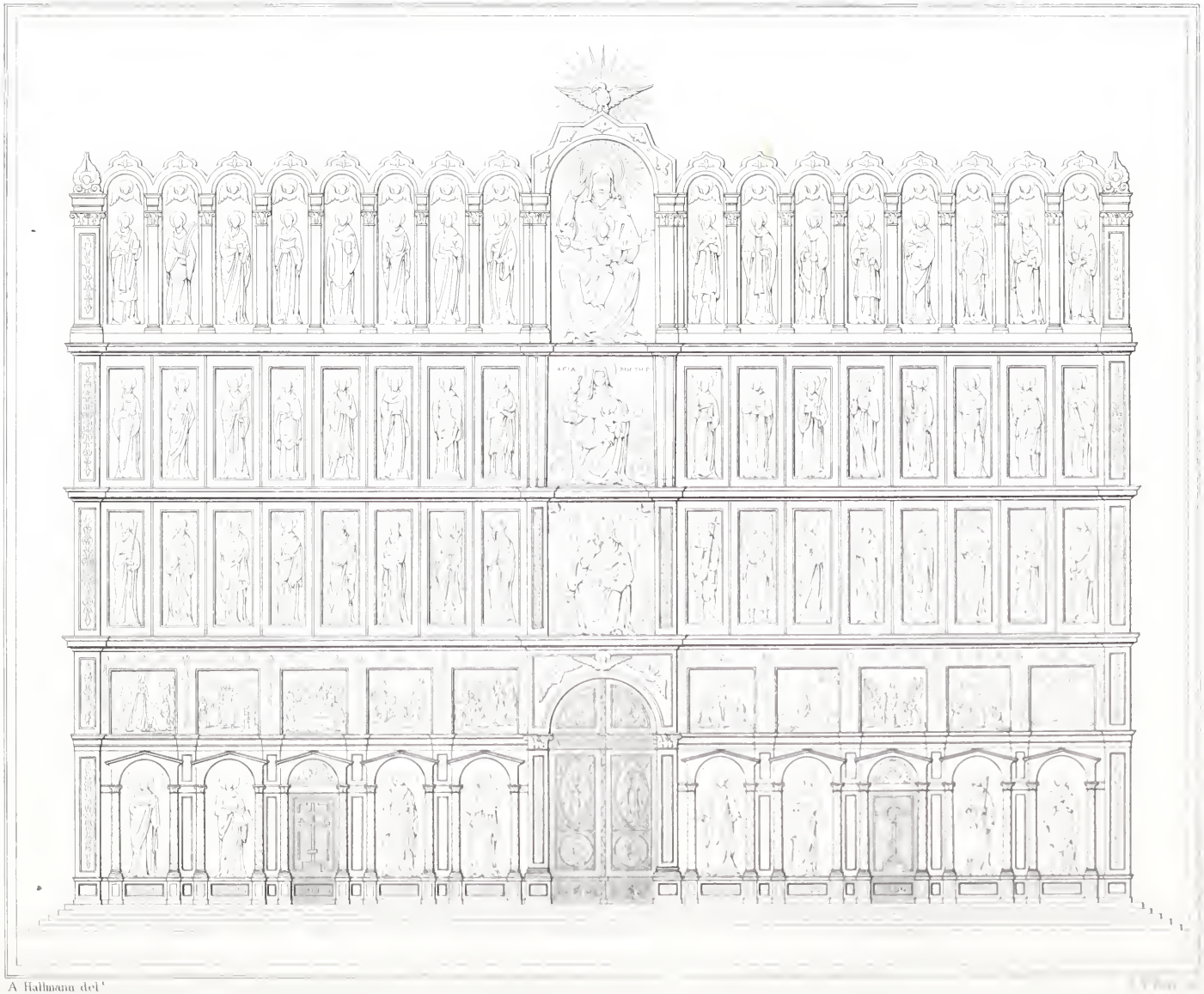
has been made, so that at the farther extremity of the edifice are seen upon the same line, three distinct Iconostases. Between the principal door and the lateral ones, there is, in front of the Iconostasis on each side, a place for the choristers, but leaving a free passage, because it is necessary during divine service to pass from one door to another. Above and before the Iconostasis always rises the principal cupola, and, in the cathedral churches, opposite the Iconostasis at the foot of the pillars which support the cupola, there is on the left a throne with a baldachin or canopy for the emperor and on the right another corresponding one for the metropolitan.

There are generally three doors of entrance to the edifice, one opposite the middle of the Iconostasis, and one on each side to the north and south, which correspond with the principal cupola, and with the transept, if it may be so termed. This is the usual distribution; but sometimes the church is elongated to the westward as at St. Sophia at Novgorod 1056; this part of that church however does not appear to be original, but rather of the same period as the bronze door, which is of the end of the twelfth century, and greatly resembles in its workmanship that of St. Zeno at Verona. Occasionally there are porches, and there is a peculiarity in the conventual churches, that they are surrounded with a kind of porch or colonnade on all sides except the east.

Another peculiarity very frequently to be observed, as regards the convents, is, that there are two churches one above the other; but that on the ground floor is generally more simple than the upper one. It would bear some analogy with the crypts of western churches, if this lower church were subterraneous; but it is on the level ground, conformably with the custom of depositing the coffins of saints or princes on the floor of the church, as may be seen in the church of St. Michael in the Kremlin. As to the situation of the cupolas, there is generally one principal cupola in the midst of four smaller ones, which surround it; and the small ones are nearly always at the four angles of the Greek cross, and do not, as at Venice for example, surmount the transept and anterior part of the nave.

Although of rare occurrence, there are some examples of these two systems being united, as at Kieff, so that each vault of the interior is covered by a cupola.

The church of St. Basil, built under Ivan the Cruel 1560, to which allusion has been already made and the plan of which is on Plate I. is of a similar disposition. The cupola in the middle is surrounded by four great and four smaller cupolas or rather towers; so that the church has the general form of a Greek cross, but there is this peculiarity, that each cupola covers a chapel



A Hallmann del.

THE ICONOSTASIS OR ALTAR SKREEN OF A RUSSIAN GREEK CHURCH

separated by a corridor from the others, and that there is in each of the chapels a separate Iconostasis: this church is also in two stories.

This building has not been without influence in the construction of several others, and there exist many octagonal churches with four smaller octagons at the side, thus forming so many sanctuaries.

Sect. 2.—*The Decoration of the Interior.*

In every church the Iconostasis is the principal feature, the point of attraction to which all the other ornaments are subordinate. An Iconostasis will therefore be described such as it exists in the ancient cathedral churches; it is needless to observe that in the inferior churches the Iconostasis was much more simple though in some particulars they are every where essentially the same.

A perfect Iconostasis is the *representation of the universe*, or rather of the *celestial kingdom*. It is composed of four or five different tiers, four of which are indispensable, as will be presently explained. Each tier is composed of an unequal number of pictures of saints, painted on tablets or long square surfaces, the position of which is rigorously fixed.

On the first tier, which rises generally a few steps above the ground, (the number of steps is indifferent provided they do not exceed seven) are three doors; the middle is a folding door, by means of which a view of the altar is obtained during the ceremony, and is ornamented with the Annunciation of the Virgin, the Virgin on one of the leaves, and the angel on the other, accompanied by the heads or emblems of the four evangelists; on the right is the effigy of Christ, on the left that of the Madonna—on the right after that of Christ, is placed the picture of the saint or of the festival of the church—then come the smaller doors already mentioned, which are single doors. Above the central door there are occasionally three angels' heads, as symbolical of the Trinity; above the smaller doors, are placed, on the left the Greek cross, on the right the cross of Moses, symbols of the new and old dispensations. Such are the indispensable arrangements of the first tier; if there be more room, it may be ornamented with other pictures of saints. Of these principal pictures only the heads, hands and feet are visible, the body is covered with a metallic clothing or drapery of silver or gold in very flat relief—the ground, like that of the whole Iconostasis and often of the entire church, is gilt. Before each picture a lamp is suspended exactly in the middle, and the pictures ought not to be higher than to allow of kissing at least the feet.

On the second tier Christ is represented in the middle, seated on a throne,

clad in pontifical robes. On the one side is St. John the Baptist, on the other the Madonna without the child—after that appear on each side two archangels and six apostles; the different tablets upon which these effigies are painted, seem in the ancient churches joined to one another without ornament,—in the more modern they are divided by little gilt columns.

On the third tier we find the Madonna in the middle seated on a throne, holding the infant Jesus on her knees; on each side of her are seen the effigies of the prophets.

On the fourth tier God the Father is represented on his throne in the centre, with the infant Jesus—on each side are the patriarchs of the church; on this last tier the effigies are surmounted by small arches, the centre one being higher than the others. As the figures in the middle are seated, they are twice the size of the others which are standing. Sometimes there is a fifth tier, which is placed either between the first and second, or between the second and third; and upon the tablets of this tier are representations of the history of the Saviour, the last supper, the passion, the crucifixion, &c.: this tier is generally only half the height of the others.

It remains yet to be mentioned that on the vault of the great cupola before the Iconostasis is generally painted an enormous head[3] of Christ, and that a great lustre nearly touching the Iconostasis is suspended before it.

The other parts of the church are ornamented with paintings on a gold ground; even the columns are decorated in this manner; but all these paintings represent miscellaneous subjects. In style they are wretched and perfectly resemble the art of the early Christian ages. The church is lighted generally by very narrow windows, perforated in the side walls, or in the drums of the cupolas; for festivals there is a great display of lustres, made of plated copper, which hang from the vaulted roof. The general internal appearance of the Greek churches is on the whole extremely solemn and imposing on account of their magnificence and mystic aspect.

Sect. 3.—*Exterior, Façade, Roof, Cupolas.*.

Respecting the ornaments and colours of the façades, there can be no doubt that they have frequently undergone changes in the course of time; because the greater part of the Russian churches is constructed of brick, or at least

[3] This occurs frequently in Roman Catholic churches of Greek origin, as in the cathedral of Monreale, where a gigantic head of our Saviour is painted in mosaic. It is also to be remarked, that these figures almost always have the name of the Saviour or saint inscribed in Greek characters in perpendicular lines. See Hittorff and Zanth's Architecture Moderne de la Sicile.

covered with plaster. But the Russian practice of painting churches with strong and crude colours had its origin in antiquity, and is very analogous to the taste of southern nations, to whom the Russians owe the form of their churches. At present the most ancient churches, those of Novgorod, Kieff, and Moscow, are whitened. With respect to general forms they are very simple; the doors are built with semicircular heads and broad architraves, with very heavy moldings and beadings; they are often surmounted by a representation of the saint, whose name the church bears, as is the church of the Assumption at Moscow by a colossal head of the Virgin. The windows, very high from the floor, are small and narrow. With respect to the upper part of the edifice, the oriental style of the eleventh and twelfth century is for the most part adopted. The horizontal line of cornice is rejected for arched forms, exhibiting the extrados of the vaults—as in the church of St. Mark at Venice. This cylindrical covering is well known in the East, and is even to be seen in Italy in the environs of Naples. These extrados of the vaults, which are analogous to their interior construction, are covered with lead, iron or copper, gilt, plated or painted in various colours. There are however many churches having a horizontal cornice, with a square roof inclined at each side of the edifice; but these are more modern, and this covering accords very ill with the cupolas, which rise from it like mushrooms, exactly at the angles of the roof. Sometimes the piers of the interior of the churches are evident on the exterior, so that the whole construction of the edifice shows itself on the façade.

The Russian churches derive a peculiar aspect from the cupolas, which rise above the roof. At the rise of ecclesiastical architecture in Russia in the eleventh century, the style prevalent in the East was naturally imitated, and the cupolas thus introduced were not such as we see for example at St. Sophia at Constantinople, or at Venice; but such as are to be met with in contemporary oriental churches. They differ principally from the cupolas of St. Sophia, in the arrangement of the windows, which are not perforated in the vault itself, but in a high cylindrical or octagonal drum, above which the cupolas are placed. The interior vault is always hemispherical.

The exterior of the drum is often decorated with little columns between narrow windows; and the form of the cupola is extremely varied. The first are conformable to the Greek originals of the eleventh century. The cupola has nearly the form of a hemisphere with a pointed apex, and the general appearance greatly resembles a helmet of the time of Charlemagne, or of the Persian form. The apex is surmounted by the Greek cross. Cupolas of this kind are met with at Novgorod and Kieff. See Plate I.

The second species of cupola is that, in which not only does the curve exceed that of a hemisphere, but the width or diameter also exceeds that of the drum which forms its base. Finally on more modern churches we observe coverings, which scarcely at all resemble their origin: these cupolas have the flat form of an onion; another variety on the contrary gives to the cupolas the form of a long pear. There are also smaller cupolas in groups, and sometimes domes terminating in slender spires. These cannot be characterised as style at all, but such a jumble of elements, Byzantine, Italian, Tartar, Turkish, and Persian, painted in all colours, give a Russian city like Moscow for example, a very peculiar character.

Sect. 4.—*A Parallel.*

It may not be uninteresting to consider the differences between the Russian, the original Greek, and the Western churches, which bear traces of Greek influence. We know that the first Christian temples, under Constantine in the East and even at Rome, were circular or octagonal, and that they were surmounted by a single dome. We see this system still employed in the octagonal church of St. Vitale at Ravenna in 547. Afterwards we find the same disposition in the interior of the churches with few variations; but the exterior assumes the square form, as in St. Sophia at Constantinople. In the interior of this church the form of a Greek cross is already indicated, and it may be regarded as the basis of the Russian churches, though they are differently disposed in other respects.

In all these, and even in those of the seventh and eighth centuries, there is in the middle of the eastern side a place for the grand altar, indicated by a great niche or round apsis most frequently evident upon the façade. The space round the altar was occupied by the seats of the priests, thus forming the choir as generally arranged in the churches of the West in all ages. At the end of the seventh century began the violent disputes between the Iconoclasts and Iconolaters. (730) The emperor Stephanus was the first who forbade all images in the Greek church, though they were adopted anew in the year 842. This war, known by the name of the Iconomachia, ended only in the great schism or rupture between the churches of the East and West, A.D. 867.

This division was likely to have important consequences on the ritual of the Greek church, and probably from this time may be dated the custom of not allowing carved images or statues in churches, except statues of angels, and this exception seems a modern reaction. It is for this reason we find merely Niellos

upon bronze doors of Greek origin—even in Italy as at Monte St. Angelo, at Canopa in Apulia, at Amalfi, Salerno, &c. &c. It is very extraordinary, that we do not meet with such doors in Russia. Perhaps the only example is that of Novgorod, but its compartments are singularly ornamented with reliefs; in style they resemble, as already noticed, the reliefs of the door of St. Zeno at Verona, and bear the general character of all the sculptures of that time. Though the date is not exactly ascertained, it is known that the door came from Germany, and it is said to have been cast at Magdeburg. It was long supposed to be of Byzantine origin, but that is impossible, for reliefs were already prohibited, and all the doors brought from Constantinople into Italy were in Niello.

A difference, not less important, and which appears also one of the consequences of the schism, was the establishing at each side of the grand altar, a secondary one; not as in Roman churches at the ends of the transept, or in side chapels, but at the extremity of the church, in the same direction as the grand altar. Their place is always indicated by a niche or apsis similar to the greater one in the middle. In the interior these niches are never absent, although on the outside there are examples where the great apsis alone is seen —the church of La Panegia Lycodino and the cathedral of Athens of the eleventh or twelfth century exhibit examples of both. In the Russian churches which took their origin in the same century (1015) we have seen, that this disposition became typical, and that it is quite conformable to the division and subdivision of the Iconostasis. It is striking to observe how Greek art is displayed in Italy in the eleventh, twelfth, and thirteenth centuries, on the coasts of the Adriatic Sea, of Sicily, and of Calabria even to the environs of Naples. The disposition just mentioned is met with in nearly all the churches of that epoch at Bari, Trani, Malfetta, Otranto, &c. &c., where the Greek worship then prevailed, and where the Byzantine style was long preserved. This situation of the altars and niches is seen, even where the churches are Roman, as at Palermo in the chapel of the castle, at La Martorana and Monreale. Even at Amalfi and Ravello all the churches have this peculiarity.

Considering that this disposition is found in churches of an earlier date, as in the church of St. Parenzo in Istria (542) at St. Maria delle Cinque Torri of the eighth century near Monte Cassino, in a church on a perfectly Greek plan at St. Fosca at Torcello near Venice, and at St. Catherine near Pola in Istria, and that perhaps even the form of the ancient basilicas, divided in three naves, might have given rise to this disposition; it may be very possible that the Greeks preserved this form as an ancient custom of the church, and that it was

the Roman church rather, which departed from it. This observation is corroborated by the descriptions of ancient writers, who tell us, that there was on the left of the altar a place for the deacons of the church, afterwards called the sacristy, and on the right an altar for the consecration of the bread and wine for the communion. In Roman churches we always see a sacristy at the side of the church, but in the Greek churches the priests always robed themselves behind the Iconostasis; and to the present day there is an altar at the side of the principal one for the preparation of the bread and wine.

It is probable that the Iconostasis of the Russian churches, as it has been described, was not yet of such ample dimensions in the eleventh and twelfth centuries. At that time the grand altar was always separated from the rest of the church by little columns or gratings, as in all Roman churches more or less: and the disposition of the church of Sta. Maria at Venice is exactly that of the Greek churches in the east, during the century in which it was constructed. We likewise see there, as at Bari and Barletta, a baldaquin or canopy over the altar.

Another reason for supposing that the Iconostasis, with that quantity of images, such as it is now in the Russian churches, dates perhaps only from the fifteenth century is, that it does not appear in the plans of the church, as forming part of the construction of the edifice, as at St. Mark at Venice, but that being always of wood it is only attached as a screen to the columns of the cupola; and that behind we observe quite a rough wood-work devoid of the slightest ornament, which is held together by bars of iron, or by an irregular wooden framing. On considering these remarks, some credit may attach to a story, purporting that a tzar, fearing lest the licentious morals of the priests of his time might provoke scandalous scenes during divine service, ordered the sanctuary to be concealed from the eyes of the faithful.

A third very remarkable difference in the Russian churches is, that there are no separate places for the women: and there is no where even a single remnant of a tribune or gyneceum, a circumstance which is the more astonishing as this disposition is met with, not only in the east, but also in nearly all the churches on the coasts of the Adriatic Sea at Bari, Trani, &c. &c. These tribunes or galleries, adopted also in Gothic churches, do not exist in the Russian churches, and it is very certain that the women have access to all parts of the church, except behind the Iconostasis; and that a great portion of their devotion consists in kissing the pictures on the Iconostasis.

Sect. 5.

As a conclusion to this dissertation, let us pause a moment to consider the modern churches erected since the time of Peter the Great especially at Petersburgh. As art in Russia was in the Middle Ages the offspring of the East, so in the reign of Peter the First the manners and arts of the North of that time were adopted, and Russian art remains to the present time in the hands of foreigners. With few exceptions all these are of a very bad style and devoid of taste with respect to form. The most ancient at Petersburgh, as that of St. Vladimir, St. Nicholas, &c. &c. still preserve the Greek cross with the five cupolas, but in a corrupt style; and as all the architects came from Roman Catholic countries, they employ the form of a Latin cross, as in the church of Kasan, of Alexander Newsky, &c. &c. Since that time at least, if not always, the clock towers have been united to the church—in ancient times they were apart from it, as is frequently the case in Italy. With respect to internal decoration, the manner of painting on a gold ground is lost, being replaced by naked and white walls. The new church of St. Isaac[1] will doubtless be the best of all these modern structures, though it has neither the form of a Greek cross, nor of a Latin one.

Recently it has been felt in Russia as in other countries, that the Middle Ages were not deficient in beauty, and that it is wrong, especially with regard to church architecture, to depart from their practice.

The consequence of this re-action has been the construction of several small churches in the ancient manner, and last year was laid the first stone of a very large church in that style at Moscow; for the ancient churches, even the cathedral, are extremely small. The architect is not devoid of talent, but unfortunately he imitates the churches of a later period in all their extravagance.

[1] This church, which is of vast dimensions, is very fully described in Dr. Granville's work on St. Petersburg, with a view of the Church, in vol. ii. pages 195-6-7, of the second edition.

REPORT OF THE COMMITTEE APPOINTED TO EXAMINE THE ELGIN MARBLES,

IN ORDER TO ASCERTAIN WHETHER ANY EVIDENCES REMAIN AS TO THE EMPLOYMENT OF COLOR IN THE DECORATION OF THE ARCHITECTURE OR SCULPTURE.

Read by W. R. Hamilton, Esq. Honorary Fellow, at the closing ordinary Meeting of the Session 1836-7, *held Monday, 24th July*, 1837.

COMMITTEE appointed by Resolution passed at the ordinary Meeting held Monday, the 5th December, 1836, to examine the Elgin Marbles in the British Museum, in order to ascertain whether any evidences remain as to the employment of Color in the decoration of the Architecture or Sculpture, and to report the result of their examination.

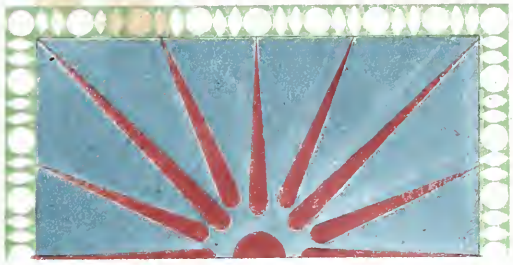
The Commitee to consist of W. R. Hamilton, Esq. Foreign Sec. Roy. Soc. of Literature; R. Westmacott, Esq. R. A.; C. L. Eastlake, Esq. R. A.; C. R. Cockerell, Esq. R. A. Hon. Fellow; Dr. M. Faraday, F. R. S. Hon. Member; and Messrs. Angell, Donaldson, and Scoles, Fellows.

Elgin Room, British Museum.—At a Meeting held on Tuesday, the 13th of December, 1836: present, R. Westmacott, Esq. R. A.; C. Eastlake, Esq. R. A.; Dr. Farraday; Messrs. Angell, Donaldson, and Scoles; as also Messrs. Forshall and Hawkins, officers of the Museum; T. L. Donaldson stated that Messrs. Hamilton and Cockerell, being at Cambridge, had written to say they could not attend.

The attention of the Committee was first directed to fragments Nos. 127 to 130 inclusive, in black, being Nos. 252 to 255 red, portions of the Ionic antæ capital and continuous mouldings of the Hexastyle Portico of the Erectheum. The object was to ascertain whether the inequalities of the surface of certain portions of the plain faces arose from a coating of some substance originally placed upon the surface of the marble, for the purpose of receiving the color or paint, or whether it resulted from the action of the weather.

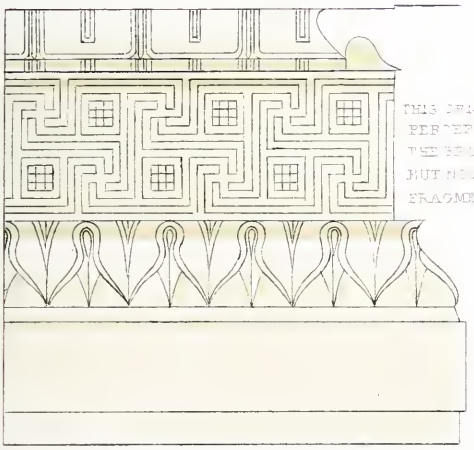
It appeared, upon examination by a powerful glass, that the raised portions,

FROM THE TRIPLE TEMPLE OF THE ACROPOLIS OF ATHENS.



FROM THE TEMPLE OF THESEUS

FROM THE TEMPLE OF THESEUS



THIS ORNAMENT IS PERPENDICULAR IN THE SEGMENT N° 200 BUT NOW OUT OF THE FRAGMENT [illegible]

FRAGMENT IN THE BRITISH MUSEUM N° 308 IN BLACK. NOW 131 IN RED FROM THE PROPYLEA OF THE ACROPOLIS

TERRA COTTA FORMERLY COLLECTION [illegible] BRITISH MUSEUM

FROM THE CAPITAL OF IONIC COLUMNS OF THE TETRASTYLE PORTICO OF THE TEMPLE TEMPLE

which remained in some parts, and which had a deeper ochrish tone than the rest of the marble, was the original surface highly polished, and that the general surface of the marble had been pretty equally worn away to the depth of about one-twentieth part of an inch by corrosion.

The ochrish tint also seemed the result of the weather, as upon examining portions of this and other blocks of marble which were broken, the fractured surface presented in some parts a like colour, produced evidently by the action of the weather, or other accidental circumstances, such as contact with the earth, &c.

The Committee then proceeded to examine the fragment marked No. 154 in black, and No. 260 in red; No. 260 being a portion of one of the beams of the Propylea of the Acropolis at Athens. The fascia presented evident marks of colored meandering ornament, and upon washing the surface the outlines of the meander were found to be marked or indented with a sharp tool. The whiter part has the surface polished, but the surface of the darker portion is rough. The Committee could not decide whether the darker tone resulted from the stain produced by the atmosphere, or rather the dust and dirt of the air, which would adhere more to the rougher surface of the marble, or whether it arose from the original application of paint or color; but the presumption is in favour of the atmosphere or dirt, as the dirt or color readily washed off with a sponge.

The Committee were unable to decide whether the parts now smooth and rough were originally in that state, or whether the part now rough has become so in consequence of the action of the atmosphere upon it, the smooth part having been protected from that action by gilding or colour.

No. 308 in black, now 131 in red, at the north end of the Elgin room, and upon which the capital from the Propylea of the Acropolis of Athens is placed, is a larger fragment of the same part of the Propylea as No. 260, and the ogee bed moulding is preserved entire, with the leaves distinctly apparent on the surface. Upon being moistened with a sponge, it was evident that the outlines of the ornamental leaves and stems were engraved with a tool[1], and that the darker parts of the ornaments were rough on the surface.

Sarti the modeller being present, who has been employed for many years by the trustees of the British Museum, being now engaged in taking moulds of the whole series of the Elgin Marbles belonging to the Parthenon, stated to the Committee that he had never been able to discover traces of paint or arti-

[1] Might not this mode of engraving the outline have been for the purpose of preventing the colour from spreading beyond the pattern, as well as for giving a sharp and distinct outline to the ornament?

ficial color on any of the figures of the bas-reliefs, metopes, or sculptures of the pediments, although his attention having been originally drawn to the subject, he had carefully examined every portion of the surface of each figure, for the purpose of ascertaining whether any traces or signs of color were to be found. He stated also that the whole surface of the marbles had been twice washed over with soap leys, subsequently to their having been moulded on former occasions, as that or some other strong acid is necessary for the purpose of removing the soap which is originally put on the surface in order to detach the plaster of the mould. Dr. Farraday was of opinion that this circumstance was of itself sufficient to have removed every vestige of color, which might have existed originally on the surface of the marble.

The Committee then proceeded to examine two Athenian tiles in Room VI. of the Townley Collection, their attention being directed to them by Mr. Hawkins.

They are of terra cotta, covered with a thin coating of fine stucco, the surface of which is decorated with the meandre, and honeysuckle, and lotus-leaved ornament, as represented in the drawing. The surface being moistened with a wet sponge, three different colors were perceptible, a white (or tone of the ground or plaster), green of a darkish untransparent tone, and a deep red in small portions, of unfrequent recurrence in the pattern or composition.

It occurred to the Committee that where these architectural enrichments were employed in large quantities, it is probable that the mode of forming them might have been similar to that adopted by decorators at the present day, known by the term stencilling. The fragment in question was hardly of sufficient length to enable the Committee to decide whether this method was adopted, or whether the enrichment was done by hand.

1*st June*, 1837.—At a meeting of the Committee held in the Elgin Room of the British Museum: present, Messrs. Hittorff, Hamilton, Westmacott, Angell, and Donaldson; the minutes of the previous meeting were read, as also the following letter:—

" Atherstone Hall, April 17, 1837.

" Mr. Bracebridge is happy to forward a memorandum of patterns and " colors from the Erectheum; they are drawn from the northern portico of " that conjoint temple of Minerva, Polias, Pandrosus, and Erectheus, so well " known in the Acropolis. This side of the temple, being so well shel- " tered from the sea breeze, has preserved its sculptured ornaments as fresh " and sharp as if lately finished; and the columns of this portico being fluted

" with capitals elaborately worked and well sheltered, have retained remains " of color. At the top of the flutings especially, a thin coat of slate-colored " paint is visible, at other points yellow and red color may be traced; but " the remaining pieces are so small, and the colors *so much* faded, as to leave " the subject in dispute; this being alone certain, that there was color once " carefully applied (at all events to the intaglio parts of the relief or concave " parts of the capitals, &c.), and that this color was of various shades; the " protuberant part of the work retains no color. The probability that blue, " red, and yellow were used is very strong. Some portions of paint might " be chipped off and subjected to analysis, which would determine what there " is, in truth, but little or no doubt of.

" Mr. Bracebridge has not examined the capital in the temple of Theseus, " said to bear marks of paint, but he believes much the same could be said of " it as above of the Erectheum.

" In the winter of 1835-6, as Mr. B. has stated in his letter to Mr. Words- " worth, printed at the end of 'Athens and Attica,' an excavation was made to " the depth of twenty-five feet at the south-east angle of the Parthenon; here " remains were found of huge blocks of marble fresh from the quarries, chip- " pings, &c. &c.; and below these, fragments of vessels, pottery, and burnt " wood. No one, who saw these, could doubt that a level was dug down to " below that where the workmen of the Parthenon had thrown their refuse " marble, in fact the level of the old Hecatompedon, of which possibly the " burnt wood may have been the remains. *Here* were found *many* pieces of " marble, and among these fragments parts of triglyphs, of fluted columns, and " of statues, particularly a female head (the hair in nearly the costume of the " present day). These three last mentioned fragments were painted with the " brightest red, blue, and yellow, or rather vermilion, ultramarine, and straw " color, which last may have faded in the earth.

" These curious specimens are carefully preserved in the Acropolis, but " much fear is entertained of their retaining the brightness of their highly con- " trasted colors for any length of time. The colors are laid on in thick " coats. The female face had the eyes and eyebrows painted. When we " consider the brilliancy of Pentelic marble when fresh worked, there appears " a reason for using colors beyond that of imitating the usages of Attica in " more ancient temples, namely, that the minutiæ of the work in many parts " would have been lost to the eye amidst the general brilliancy."

Mr. Donaldson informed the Committee, that having in his possession

various portions of coatings taken by him from several buildings at Athens, he had forwarded them to Dr. Faraday, Hon. Member, with the request that he would be pleased to furnish the Committee with his opinion upon the composition of such portions of coatings; to which he had received the following reply.

" Royal Institution, 21st April, 1837.

" My dear Sir,

" I return you the box, with the remains of the samples.

" A. Portion of coating taken from the antæ of the Propyleum. The blue " produced by carbonate of copper: wax being mingled with the color.

" B. Portion of coating taken from the soffits of the mutules of the The- " seum. The blue is a frit or vitreous substance colored by copper. Wax " is present here.

" C. Portion of coating taken from the columns of the Theseum. I am " doubtful about this surface. I do not find wax or a mineral color, unless it " be one due to a small portion of iron. A fragrant gum appears to be present " in some pieces, and a combustible substance in all. Perhaps some vegetable " substance has been used.

" D. Portions of coatings from the caissons or lacunaria of the Theseum. " The blue is a copper frit or glass, with wax.

" E. Portions of coating from the northern wing of the Propylea. The " color, a carbonate of copper. Wax is present.

" F. Ditto, ditto (north wing Propylea), as E.

" I also return you the drawing and the letter.

" Ever truly yours,

" T. L. Donaldson, Esq. &c." *(Signed)* " M. Faraday."

In order to ascertain whether a portion of the surface of the statues of the Fates, which presented an ochrous tint and a more glossy surface than the other parts, was due to some foreign matter artificially applied to the surface, some parts were peeled off easily from the back of one of the figures on the application of a penknife. These were also submitted to Dr. Faraday, who reported as follows.

" Royal Institution, 8th June, 1837.

" My dear Sir,

" The particles you sent me seem to have come from a prepared surface. " Being put into a dilute acid, a portion of adhering matter is dissolved, and " the principal portion is left in an untouched and cleaner state. Being " then washed and dried, it is found that this consists of carbonate of lime

" and a combustible substance which protects the carbonate from the acid.
" This combustible substance when heated is destroyed, leaving charcoal, and
" then acid can attack the calcareous matter. The combustible substance may
" perhaps contain wax, but it does not present undeniable traces of that body.
" It is in small quantity as compared with the wax present in Mr. Donaldson's
" specimens. There is no mineral color present in the particles, except it
" may be a small portion of iron color, and that I rather judge to be acci-
" dental. Whether or no any animal or vegetable color had been used is
" more than I can say. " I am, dear Sir,

" Very truly yours,

" W. R. Hamilton, Esq. &c." *(Signed)* " M. Faraday."

The Secretary also submitted to the Committee various portions of glass eyes, which he had taken from the torus between the volutes of the Ionic columns of the tetrastyle portico of the Triple Temple in the Acropolis of Athens. They are of four various colors, and were arranged in the order shown on the plate.

On this occasion also Monsieur Hittorff, having a series of drawings of his restoration of the Temple of Empedocles at Selinus, restored by him and colored in its several parts according to his opinion of the polychromatic system as applied to architecture, favored the Committee with a full explanation of the grounds, upon which he had applied color to the various parts of the edifice.

The Committee then proceeded to examine the several marbles alluded to in the first report, and were satisfied with the accuracy of the former observations of the Committee.

Upon a consideration of all the facts contained in the preceding minutes, it appears to the Committee, that there remain no indications whatever of color artificially applied upon the surface of the statues and bas reliefs, that is, upon the historical sculpture. That, according to Dr. Faraday's opinion, those portions of the marble, which from the tone and surface might be supposed to be the result of color applied thereon, are the original surface of the marble stained by the atmosphere, the presence of iron in the marble, or by some such natural cause. That some of the architectural fragments present indisputable traces of tone indicative of regular architectural ornaments, and that the outlines of such ornaments are distinctly traceable, being marked with a sharp instrument upon the surface of the marble. The Committee cannot positively state, from the appearance of the marble, that such tones have been produced

by color, as they think that none of the color itself remains, but that the indication of tone results from mere variation of surface. Judging, however, from the information contained in Mr. Bracebridge's communication, there appears no reason to doubt that color has been applied. This is confirmed by the portions of coatings brought from Athens by Mr. Donaldson and analyzed by Dr. Faraday, who has detected frit or vitreous substance and carbonate of copper mixed with wax and a fragrant gum. This analysis proves that the surface of the marble of the shafts of the columns of the Theseum, and other parts of the edifices from which these specimens were taken, were covered with a colored coating. The glass eyes also of the Ionic capitals of the tetrastyle portico in the Acropolis at Athens, prove, that various materials were employed by the Athenians in the decoration of the exterior of their marble buildings.

But although the statues and bas reliefs of the Parthenon, at least those portions of them preserved in the Elgin collection, do not afford any evidence of the use of color, yet there is a constant repetition of small circular holes in the horses' heads and manes, and in one hand of each rider, showing that there had been originally bridles and straps to the horses, either of metal, leather, or some other similar substance. Similar holes are perceptible in the statue No. 94 (in red) of Proserpine, one of the two female figures of the eastern tympanum of the Parthenon, called also the Seasons or Hours; they are in the arm just above the wrist, apparently for the purpose of attaching bracelets, and in the shoulders at the junction of the drapery, as though a metal rosette had been affixed there. On the neck of one of the Fates No. 97 (in red) are also two holes, which seem to have been for a necklace. In the back of the torso of Victory, No. 96 (in red), are large holes, in which it is supposed bronze wings were fastened. No. 101 (in red) is a fragment of the upper part of the head[2] of Minerva; the sockets of the eyes are hollow, and were evidently filled with metal or with colored stones, and holes remain in the upper part of the head, affording the presumption that there was originally a bronze helmet attached to the marble. The angles of the Ægis of No. 102 (in red), which is a fragment of the statue of Minerva, one of the principal figures of the western pediment, are drilled with holes, by which the metallic serpents were attached, and in the centre a head of the Gorgon.

THOS. L. DONALDSON, Hon. Sec.

[2] This fragment alone may *perhaps* be considered as an exception to the previous statement, that no evidences of color existed on the statues or figures of the Parthenon. The hair appears to have a red tint, which becomes distinctly apparent upon the application of water.

CONSTRUCTION.

SOME PARTICULARS RESPECTING THE COST OF CERTAIN PUBLIC BUILDINGS.

BY HERR BEUTH,

PRIVY COUNSELLOR OF H. M. THE KING OF PRUSSIA, AND HONORARY AND CORRESPONDING MEMBER.

Read at the Ordinary Meeting, July, 1840.

"To Thomas Donaldson, Esq. Corresponding Secretary of the Royal Institute of British Architects.

"Berlin, 5 June, 1840.

"DEAR SIR AND COLLEAGUE,

"I AM happy in being able to give you the following account of the expense "of buildings erected by the Government, for which you have asked me in "your letter of the 2nd of April. I am able only now to fulfil your request, "being occupied from morning till night in heavy public business. I am sorry "to cause you the trouble of transcribing my broken English, but I hope it "will be intelligible. It is difficult for a man sixty years old, and so engaged "as I am, to improve. This notice would not have been of practical use without entering into some particulars; but it has been connected with some "trouble to give you the latter, in some instances, as it has been necessary "to take them out of old forgotten accounts.—I have the honour to be, Sir, "with every sentiment of respect,

"Your very obedient servant,

"BEUTH."

N.B. In the following tables the quantities and amounts have been reduced into equivalent English measures and sums, for the convenience of the English reader:—1 Prussian foot linear = 12·358 English inches; 1 Prussian foot super. = 152·72 English super. inches; 1 Prussian foot cube = 1887·313 English cubic inches. Forty-eight Prussian dollars are considered equal to seven pounds sterling English.

No. 1.—BERLIN MUSEUM. (Vide Schinkel's Architectonische Entwuerfe, Plates 37, 42, 103, 108.)

The cost of building the Museum and connecting buildings and works, &c. was as follows, viz.—

	£.	s.	d.	£.	s.	d.
Foundation.—Piling the river upon which the Museum was built, with 3057 piles, driven from 43 to 53 feet in the ground, the construction of the piers and vaulting, and the foundations throughout to the level of the plinth of the building, cost . . .				22,233	13	0½
The Superstructure, with the exception of the two Dioscuri and the figures on the corners, and the large staircase in front, but including all other internal and external decoration, cost	64,079	12	3			
The large staircase in front cost . . .	1,107	11	7½			
The two dioscures and the figures on the corners cost	3,237	10	0			
				68,424	13	10½
Purchase of certain buildings and ground for erecting the new buildings upon, for purposes connected with the Museum, the erection of the said buildings, and the new bridge, cost				27,855	14	5
Total				118,514	1	4

The ground covered by the Museum, 284 ft. 4½ in. long, by 175 ft. 4 in. deep. Deduct two court yards, 58 ft. 8 in. long by 54 ft. broad, leaves the nett superficies built on 43,636 square feet.

The cost of erecting this building, which rises to an elevation of from 63 ft. 9 in. to 84 ft. 5 in. is to a fraction, per square foot .	1	10	7½
The cost of the foundation being 22,233*l.* 13*s.* 0½*d.* the expense per square foot is	0	10	1¼
Making a total cost per square foot, including all external and internal decoration, of	2	0	8¾

No. 2.—The INSTITUTE or SCHOOL of ROYAL ARCHITECTS.

(See Schinkel's work, Plates 121, 124, 126.)

	£.	s.	d.
The cost of the foundations, which were difficult and expensive to form, was	4,425	17	4
That of the superstructure, excepting the large stairs in front of the building	25,958	6	7
That of the stairs and footways in front	495	7	8
Total	30,879	11	7

The ground covered by the building is 151 ft. square, from which deducting the court yard, 50 ft. 5 in. by 31 ft. 11 in. leaves the nett superficies built on 21,241½ square feet.

The cost of the foundations, under the cellars or basement story, was, per square foot	0	4	1¾
That of the basement and superstructure	1	4	4
Total	1	8	5¾

The external walls were faced with finely polished, partly glazed bricks; the mouldings of the architectural decorations in brick, which with the models made by artists for the terra-cotta basso-relievos were charged 3,992*l.* 3*s.* 8¼*d.*; this is equal to a cost per foot superficial on the face of the walls of court yard of 5½*d.* and on the face of the external fronts, per foot, of 1*s.* 10*d.* which may be taken as the average cost of refined execution in burnt clay of this description.

No. 3.—The WERDER CHURCH in Berlin (see Schinkel's work, Plates 79 and 84) was also executed in brick with basso-relievos; total cost, including the interior decorations, pictures, &c. &c. was 29,465*l.* 17*s.* 5*d.*

No. 4.—The THEATRE ROYAL at Berlin. (See Schinkel's work.) The building, including machinery, basso-relievos, statues, the Nereids and Pegasus of copper, cost (in round numbers) 94,810*l.*

The ground covered by the Theatre, including that occupied by the large stair in front of the building, is 37,058¾ square feet. After deducting the expense of the stairs, which was 1,458*l.* 6*s.* 8*d.* the cost per square foot covered is 3*l.* 4*s.* 10*d.* notwithstanding that the foundations have not been difficult, only

11⅓ ft. deep, which, compared with the Museum and the Institute of the Architects, shows the cost per foot of the Theatre much the greatest. Thus the Theatre Royal, with ordinary foundations, per square foot, 3*l.* 4*s.* 10*d.*; the Berlin Museum, with piled foundations, 2*l.* 0*s.* 8¾*d.*; and the Architectural Institute, with difficult foundations, 1*l.* 8*s.* 5¾*d.*

No. 5.—The KING'S "CORPS DE GARDE" cost 10,977*l.* 19*s.* 3*d.* (See Schinkel's Entwuerfe, Plates 2, 3, and 4.)

No. 6.—THE CASINO at Potsdam, also given in Schinkel's work.

	£.	*s.*	*d.*
Originally estimated expense	9,988	18	8½
Extra expense for the foundations in a deep moor . .	2,916	13	4
Total cost	12,905	12	0½

No. 7.—THE NEW CHURCH at Potsdam. (Schinkel's work, Plates 133, 136.)

As the king did not approve of the cupola it is still wanting, but the building is so constructed as to allow of it being executed at a future time.

The general expense is 47,824*l.* 7*s.* 3*d.*

The surface of ground overbuilt by the church, the niche of the altar, and the portico, is (Prussian $118 \times 118 + \frac{30}{2} \times \frac{22}{7} + 68 \times 38$), and contains 17,922 Prussian feet, or 19,042⅛ English feet superficial.

The height to the top of the cornice is 85 ft. 5¼ in. and to the top of the pediment 103 feet.

This latter has been built instead of the originally intended cupola, the height of which was to have been 226½ feet above the level of the floor of the church. It is to be observed that the foundations and the dimensions of the rough building have been increased, also the circular vault of 61¾ ft. diameter has been built originally in contemplation of the future erection of the cupola, and are therefore more massive than required to support the present flat roof of the church.

The cost has been as follows, viz.

	Total amount.	Amount for one foot of ground overbuilt.
1st. Masons' work, materials included for the whole building, including foundation, 13 ft. 4½ in. deep	£. 19,847 18 4	1 0 8

	Total amounts. £.	s.	d.	Amount for one foot of ground overbuilt. £.	s.	d.
2nd. Stonecutters' work, for the internal and external columns, architraves, stairs, &c. including the sandstone from the quarries .	7,525	0	0	0	7	10
3rd. Carpenters' work, including scaffolds, centering of the large spanned vault, &c. &c. .	3,310	8	4	0	3	7
4th. Gilders' and Coppersmiths' work, including the cast zinc tiles to cover the roof . .	2,143	15	0	0	2	3
5th. General preparatory works, viz. enclosing the ground, erecting office for superintendants, and sheds for stonecutters, &c. .	1,254	3	4	0	1	4
Exterior: the large basso-relievos of the two tympanums of the pediments, the figures on the inscription tablets, the acroteria sculptures, the figures in the foliage of the Corinthian capitals, the large and richly decorated cimatia round the whole building, &c. Interior: joiners', locksmiths' works, painting, &c. the large cast iron windows, figures, arabesque ornaments, the pulpit and organ richly decorated with sculptures cast in zinc, the picture of the niche of the altar upon a gilded ground, the altar and baptismal font of black marble	10,981	5	0	0	11	5½
Laying out the ground around the church, paving broad footways, &c. . . .	875	0	0	0	0	11
Architect's fees, salary of clerks of works, accountants, &c. for 7½ years . . .	1,895	16	8	0	2	0
Total cost	47,833	6	8			
Ditto per foot . . .				2	10	0½

No. 8.—THE CASTLE BRIDGE at Berlin. (Schinkel's work, Plate 24.)

The statues upon the pillars, to be of polished granite, are still wanting. Total cost, 39,887*l.* 13*s.* 1*d.*

BUILDERS' AND WORKMEN'S PRICES, COST OF MATERIALS, ETC. AT BERLIN.

Mason or Bricklayer and Plasterer.

For the last eighteen years it has been usual for the master mason, who provides the workmen and labourers, and sends them out on day-work, to pay them the following wages, and to receive the profit added for his trouble, viz. per day of twelve hours:

	Wages paid by Master.	Add Master's Profit.
	s. *d.*	*s.* *d.*
The polisher, or best man	2 11	0 3
Common journeyman	1 11½	0 3
Apprentice	1 2½	
If he be already useful		0 6
Labourer	1 2½	0 1½

It is also customary for master masons, when they have undertaken the erection of buildings by contract, merely to build the walls and vaults by day work, and let out to their workmen the finishing of the works internally and externally by contract or as piece-work, at which the best and most diligent workmen usually earn, per day of thirteen hours,—

Journeymen	2 11
Labourers	1 6

For fine finishing works in lime, stucco, or English cement, which is always done by the workmen as day-work, also for water works, and difficult foundations, where the men have to stand in water, they receive an addition to their daily pay of 3*d.* for twelve hours.

For instance, the polisher, or best man at cement	3 2
The common journeyman at foundations	2 2½

Carpenter and Joiner.

	Wages paid by Master.	Add Master's Profit.
	s. *d.*	*s.* *d.*
Carpenters' wages generally average the same as masons, the exact amount depending on the skill or competency of the individual, and the nature of the work. Twelve hours per day.		
The usual wages for day work is, for a competent "staircase man"	2 2½	
For a good journeyman	1 11½	
And for the common carpenter	1 9	
When the master carpenters give to their men as piece-work the preparing and laying of floors, wainscotting of walls, and ceilings, &c. they are able to earn thereby, at 12 to 13 hours per day, from 2*s.* 5¼*d.* to	2 11	

Stonecutters.

The journeymen stonecutters have generally their work by contract, or as piece-work, and seldom do more than re-work and reset, &c. old sandstones by the day, average twelve hours.

For day-work the journeymen's wages average . .	2 11	. . 0 2½
To which is to be added, for furnishing and sharpening tools		6
For work executed by the journeyman by measure and value, a clever and industrious man will earn per day from 3*s.* 11*d.* to	4 4½	
And the master's profit will be from 1*s.* 5½*d.* to . .		1 11½

The following are a few of the master stonecutter's prices, viz.—

	s. *d.*	*s.* *d.*
For "rough-hewn" work, per foot superficial, from .	0 2½	to 0 3
For working, clearing, and jointing, ditto . . .	0 3¼	
For rubbing face of work, ditto, from	0 4½	to 0 5
For clean worked and fine polished joints, ditto, from .	0 6¼	to 0 7¼
For circular plain work on pillars, ditto, from . .	0 8½	to 0 10

Materials.

The price for sandstone roughed to the scantling is as follows, viz.:—

	s.	d.		s.	d.
For that commonly used, from the quarries on the borders of the Elbe near Dresden, and water carriage (by contract) to wharf, in pieces not exceeding 87¼ cubic feet, per foot cube	1	0	to	1	1
Add carriage from wharf to building	0	1½	to	0	1¾
Total	1	1½	to	1	2¾
For a finer grained kind of sandstone named Cotta, from quarries near the town of Cotta, more distant from the borders of the Elbe, the price is 1¾*d.* to 2½*d.* higher, on account of the additional land carriage (it however is only useful for internal work) per foot cube	1	3¼	to	1	5¼
For large scantlings, which are troublesome and awkward to handle and carry or transport, the cost increases in proportion. Thus pieces containing 273⅔ cubic feet, worked at the Museum of Berlin, cost per cubic foot	1	11½			
A very fine grained and strong sandstone is had from Pelpke, in Brunswick, but in consequence of there being six miles land carriage from the quarry to Magdeburg, the cost per foot cube is from	2	2½	to	2	8

Besides, the working of these stones is very costly, as they are nearly as strong and hard as marble.

The trials which have been made with the stones from the Prussian quarries near the borders of the river Unstrut, have hitherto not been attended with success, as the stone is of a more shattery nature, and is more costly, than that from the borders of the Elbe.

It is to be observed that, with these sandstones, in ordering the scantlings from the quarry, an allowance of an inch on each face must be made for working; for example, a stone for a column to be worked 2 ft. by 2 ft. and 6 ft. long, must be ordered 2·2 × 2·2 × 6·2.

	s.	d.		s.	d.
The granite for building purposes is to be had in the rough or worked, according to the use for which it is intended, and according to the size of the stones. The cost varies, in large pieces roughed to nearly due form, per foot cube from	4	5¼	to	7	11½
And the cost of finishing, grinding, and polishing the foot superficial amounts to about				16	5
Tolerably well worked stair steps, full squared in view, 14⅜ in. broad, cost per running foot, including the price of the stones at the building	2	5¼	to	2	11
Square stones for foot pavement, 4⅛ in. to 5⅛ in. thick, from Silesia, including the cost of five miles land carriage and sixty by water, costs per foot superficial	0	9½			
And with the laying of them, costs	0	11			
Marble of a greyish white colour, including the cost of carriage eleven miles by land and sixty by water, costs per foot cube	6	2¼	to	6	7½
Working the same costs, with polished surface, per foot superficial	3	2½	to	3	8

Timber.

The present cost of insquared pine timber, in trees, varies according to the size and quality, per foot cube, from	0	4½	to	0	5¾
Some time ago the price of sawed timber from Poland was per cube foot	0	8¼			
But at present, if full squared and of large girt, and forty lengths or thereabouts, it costs, per foot cube	0	10	to	0	10¾
And in short pieces of a tolerable girt	0	9	to	0	9½
Deals and boards, according to their fineness, cleanness, and dryness, cost more or less as follows, viz. deals, 20 ft. 7 in. × 12⅓ in. and 1¼ in. full thick, costs, the best quality, per piece, from	3	11	to	4	1½
And the worst quality, only fit for coarse purposes, per piece, from	2	5¼	to	2	7½
And per foot cube, the same scantlings cost, best quality, from	1	5	to	1	6¾
Ditto, worst quality, from	0	10¾	to	1	0

Bricks.

	Per thousand. £.	s.	d.	£.	s.	d.
Size for practical purposes, $10\frac{3}{8} \times 4\frac{7}{8} \times 2\frac{5}{8}$, solid contents $152\frac{8}{11}$ cubic inches.						
The prices of bricks are very variable, but the average for the last sixteen years may be taken as follows, viz.:—						
1st, for extraordinary fine facing bricks (which have been made use of in the Architectural Institute of Berlin) from	3	4	2	to 3	10	0
2nd quality, made with cleaned clay . .	1	17	11	to 2	6	8
3rd quality, the very hard and durable sort, which are fit for waterworks, as well as for fireproof buildings	1	15	0	to 2	9	7
4th quality, the hard, well baked sort, fit for buildings 80 ft. high	1	10	$7\frac{1}{2}$	to 1	17	11
5th quality, the common sort, only fit for light buildings	1	1	$10\frac{1}{2}$	to 1	12	1

Cost of Foundations.

To make 157 cubic feet of ordinary foundation in Berlin costs as follows:—

	£.	s.	d.
For excavating the ground or trenches ($2\frac{1}{2}$ times the quantity in masonry) $392\frac{1}{2}$ cube feet per yard cube . . .	0	2	11
Workmanship on 157 cube feet of rubble (lime) stone masonry, including mixing of mortar and attendance .	0	8	9
Filling in the trenches and ramming earth $235\frac{1}{2}$ cube feet .	0	1	$5\frac{1}{2}$
For furnishing the scaffolding and tools 6 per cent. on the amount for labour	0	0	$9\frac{1}{2}$
Amount for work	0	13	11

Materials.

$1\frac{1}{3}$ cords, of $88\frac{1}{3}$ cube feet each, or $117\frac{3}{4}$ cube feet, of large (or bond) stones, at 19*s.* $5\frac{1}{2}$*d.* per cord, including land and water carriage	1	5	$11\frac{1}{4}$
$\frac{1}{3}$ cord, or $29\frac{3}{4}$ cubic feet of small stones, at 13*s.* $7\frac{1}{2}$*d.* per cord .	0	4	$6\frac{1}{4}$

	£.	s.	d.
24 cubic feet of slaked lime, slaking and transport included	0	5	$8\frac{1}{2}$
48 ditto ditto of sand	0	2	$10\frac{3}{4}$
Add for removing the superfluous earth and rubbish	0	3	$10\frac{3}{4}$
Amount for 157 cubic feet	2	17	$0\frac{1}{2}$
Or per cubic foot	0	0	$4\frac{1}{3}$
And per cubic yard	0	9	$11\frac{1}{3}$

Brickwork.

Average cost of making 157 cubic feet of brickwork (that is, 4 cubic feet more than half a rod).

	£.	s.	d.
For workmanship (as day work), including the labour in erecting scaffolds for houses three stories high	0	9	$8\frac{3}{4}$
To furnishing tools and the materials for scaffolds	0	0	7
To 1500 hard well-baked bricks, including carriage, at 1*l.* 16*s.* $11\frac{1}{2}$*d.* per thousand	2	15	$5\frac{1}{4}$
$19\frac{9}{11}$ cubic feet slaked lime	0	4	8
$39\frac{3}{11}$ ditto ditto sand	0	2	$2\frac{1}{4}$
Cost of 157 cubic feet of brickwork	3	12	$6\frac{1}{4}$
And cost of 306 cube feet, or 272 reduced, or one English rod	7	2	$4\frac{1}{2}$
Or per foot cube	0	0	$5\frac{1}{2}$

External Plastering.

Cost of executing 17 yards superficial of external lime plastering, marked in courses to imitate stone, and coloured.

	£.	s.	d.
Workmanship, including labour in erecting scaffolding	0	4	$4\frac{1}{2}$
Furnishing tools and materials for scaffold	0	0	$3\frac{1}{2}$
$4\frac{4}{11}$ cubic feet slaked lime	0	1	$0\frac{1}{2}$
8 ditto sand	0	0	6
For colouring in fresco	0	1	$2\frac{3}{4}$
Total cost of 17 yards	0	7	$5\frac{1}{4}$
Cost of one superficial yard	0	0	$5\frac{1}{4}$

Roof Covering.

The public buildings at Berlin, that have been built within the last twenty-four years, have been covered with zinc plates.

In 1817, or thereabouts, when the quintal (110 Prussian pounds) cost 2*l.* 14*s.* 5*d.* the price of that kind of roof covering was as follows, viz.:—

	£.	*s.*	*d.*
For covering the roof with boards, per superficial foot . .	0	0	3
Ditto ditto with zinc	0	1	6
Total cost per foot superficial . . .	0	1	9

At present, when the quintal of zinc costs only 1*l.* 5*s.* 3*d.* the cost per foot is—

For covering with boards	0	0	2	to	0	0	3
Ditto with zinc	0	0	6	to	0	0	7
Total cost per foot, from . .	0	0	8	to	0	0	10

Although the cost of zinc covering for roofs has so much diminished, it is nevertheless for some time back getting into disuse. That which now has the preference is asphalt. A mixture of loam and tanner's bark is also at present used for roofs covered with coal tar.

Iron.

The price of wrought iron for building purposes is at present, per Prussian pound	0	0	$2\frac{1}{2}$	to	0	0	$3\frac{3}{4}$
Per quintal	1	4	$0\frac{3}{4}$	to	1	15	0
And the price of cast iron per quintal . . .	0	12	$4\frac{3}{4}$	to	1	0	5

Beuth.

OBSERVATIONS ON THE HEIGHTS OF ENTABLATURES.

BY JOSEPH GWILT, F.S.A. F.R.A.S.

RULES in the fine arts are founded on nature or reason, and though their origin be not immediately apparent, if any rule have for a long period become conventional among the professors of an art, we may be certain that the ground of its adoption will generally become known by tracing it up to first principles. This observation is induced by a recent investigation of the practice not often departed from by architects, and indicated in most elementary books, of assigning to the heights of the entablatures of the different orders one-fourth of the height of the column of the order. Chambers, in his work, says, and truly, that such was the practice of the ancients, who rarely exceeded or fell short of that proportion. Whether this rule is empirical is at all events worth inquiry, though what follows may not satisfactorily account for it. The writer is not aware of any previous attempt of the sort having been made, although the principles developed in Lebrun's Théorie de l'Architecture Grecque et Romaine, deduite de l'Analyse des Monumens Antiques, fol. Paris, 1807, if carried through correctly, seem to point to the reason of the practice.

One of the most obvious principles of proportion in respect of loads and supports, and one apparently founded on nature herself, is, that a support should not be loaded with a greater weight or mass than itself, or, in other words, that there should be an equality between weights and supports, or in the case in point, between the columns and entablature. In respect of the voids below the entablature between the columns or supports, a great diversity of practice seems to have prevailed, inasmuch as we find them varying from 1·03 to 2·18, unity being the measure of the supports. Lebrun makes the areas of the supports, weights, and voids equal to one another; and in what I would term the monumental examples of the Doric order, such as the Parthenon, &c. he seems borne out in the law he endeavours to establish; but in the lighter

examples, such as the temple (Ionic) of Bacchus at Teos, where the supports are to the voids as 1 : 2·05, and in the temple of Minerva Polias, where the ratio is as 1 : 2·18, he can scarcely be considered correct; indeed there hardly seems a necessity for such a limitation of the voids as he prescribes, seeing that without relation separately to the weight and support, stability would be obtained so long as the centre of gravity of the load fell within the external face of the support. If it be admitted that, as in the two examples above mentioned, the voids should be equal to the weights and supports jointly, we have a key to the rule, and instead of being surprised at the apparently strange law of making the entablature one-fourth of the height of the column, we shall find that none but the result assumed can flow from the investigation.

In *fig.* 1, let A B be the height of the column, and let the distance between the columns be one-third of the height of the column = C D. Now if A B be subdivided into four equal parts at *a*, *b*, and *c*, and the horizontal lines *a d*, *b e*, and *c* f, be drawn, also if C D be divided horizontally into four equal parts, and lines be drawn perpendicularly upwards intersecting the former ones, the void will be divided into sixteen equal parallelograms, one-half whereof are to be the measure of the two semi-supports. B C and D E being then made equal to one-fourth of C D, it will be manifest from inspection that the two semi-supports will jointly be equal to eight of the parallelograms above mentioned, or one-half of the void. We have now to place the entablature or weight A G H I upon the supports or columns, and equal to them in mass. Set up from A to F another row of parallelograms, each equal to those above mentioned, shown on the figure by A F K I. These will not be equal to the supports by two whole parallelograms, being in number six only instead of eight: dividing therefore 8, the number in the supports, by 6, the number already obtained, we have 1·333, &c. which is the height A G must be, that the weight may exactly equal the supports exceeding one quarter of the height of the column by $\frac{333}{1000}$ of such quarter, a coincidence strongly corroborative of the reason on which the rule is founded. From an inspection of the figures 1, 2, and 3, it is evident that when the void is $\frac{1}{3}$ of the height of the columns in width, the columns will be 6 diameters in height; when $\frac{1}{4}$ of their height, they will be 8 diameters high;

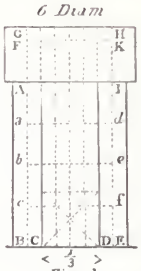


Fig. 1

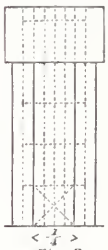


Fig. 2.

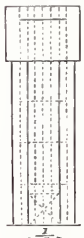


Fig. 3.

and when $\frac{1}{5}$ of their height, they will be 10 diameters high: also that the intercolumniation called systylos, or of two diameters, is constant by the arrangement. Trying the principle in another mode, take *fig.* 4 as the general form of a tetrastyle temple, wherein the columns are assumed at pleasure 8 diameters in height. Then $4 \times 8 = 32$, the area of the supports, and, as to fulfil the conditions, the three voids are equal to twice that area, or 64; they must consequently on the whole be equal to 8 diameters, for $\frac{64}{8} = 8$, and the whole extent therefore will be equal to 12 diameters of a column. To obtain the height of the entablature, so that its mass may equal that of the supports, as the measures are in diameters, we have only to divide 32, the columns, by 12, the whole extent of the façade, and we have two diameters and two-thirds of a diameter for the height of the entablature, making it a little more than one-quarter the height of the column, and again agreeing in terms of the diameter with many of the finest examples of antiquity, or nearly so. If the pediment be employed, it is evident that if the dotted lines A C, C B, be bisected in *a* and *b* respectively, the triangles A E *a*, *b* B F, are equal to *a* D C and D C *b*, and the loading or weight will not be changed. Similar results are obtained in *fig.* 5, where the height is 10 diameters, the number of columns 6, the whole therefore 180, the supports being 60. Here $\frac{60}{18} = 3\frac{1}{3}$ diameters will be the height of the entablature.

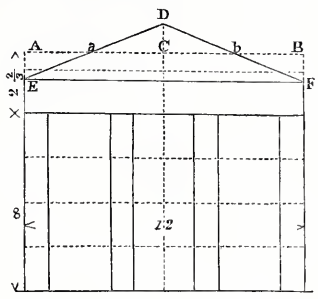


Fig. 4.

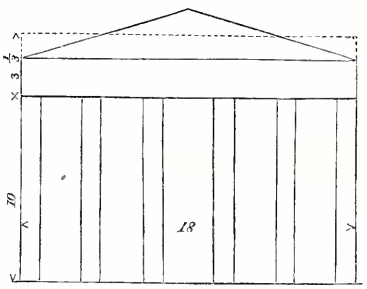


Fig. 5.

This view of the law is further borne out by analysis of the rules laid down by Vitruvius, book iii. chap. 2—rules which were not his own only, but the result of the practice of the time in which he lived, and which within small fractions are most singularly corroborative of the soundness of the hypothesis of the voids being equal to twice the supports. Speaking of the five species of temples, after naming the different intercolumniations, and recommending the eustylos as the most beautiful, he thus directs the formation of temples with that interval between the columns:—

"The rule for designing them is as follows. The extent of the front being given, it is, if tetrastylos, to be divided into eleven parts and a half, not including the projections of the base and plinth at each end; if hexastylos, into eighteen parts; if octastylos, into twenty-four parts and a half. One of either of these

parts, according to the case whether tetrastylos, hexastylos, or octastylos, will be a measure equal to the diameter of one of the columns."—"The heights of the columns will be eight parts and a half. Thus the intercolumniations and the heights of the columns will have proper proportions." Further on, in the same chapter, he gives directions on aræostyle, diastyle, and systyle temples, on which it is unnecessary here further to enlarge. Let the above directions be now examined.

The tetrastylos is $11\frac{1}{2}$ parts wide and $8\frac{1}{2}$ high; the area, therefore, of the whole front will be $11\frac{1}{2} \times 8\frac{1}{2} = 97\frac{3}{4}$. The four columns will be $4 \times 8\frac{1}{2} = 34$, or a very little more than $\frac{1}{3}$ of the whole area, the remaining two-thirds, speaking in round numbers, being given to the intercolumns or voids.

The hexastylos, *fig.* 5, is 18 parts long and $8\frac{1}{2}$ high; the whole area, therefore, is $18 \times 8\frac{1}{2} = 153$. The six columns will be $6 \times 8\frac{1}{2} = 51$, or exactly one-third of the whole area, the voids or intercolumns occupying the remaining two-thirds.

The octastylos is $24\frac{1}{2}$ parts in extent and $8\frac{1}{2}$ in height. Then $24\frac{1}{2} \times 8\frac{1}{2} = 208\frac{1}{4}$. The eight columns will be $8 \times 8\frac{1}{2} = 68$, being a trifle less than one-third of the whole area; and the voids or intercolumns about double, or the remaining two-thirds.

The average of the intercolumns in the first case will be $\frac{11\frac{1}{2}-4}{3} = 2\frac{1}{2}$ diameters.

——————————— in the second case will be $\frac{18-6}{5} = 2\frac{2}{5}$ ditto.

——————————— in the third case will be $\frac{24\frac{1}{2}-8}{7} = 2\frac{357}{1000}$ ditto.

A discrepance between practice and theory ought not to be allowed to shake the principle; hence there is no hesitation in candidly submitting a synoptical view of some of the most celebrated examples of antiquity in which a comparison is exhibited between the voids and supports: certain it is that in each case the former exceed the latter, and that in the early Doric the ratio between them nearly approached equality. In comparing, however, the supports with the weights, there is every appearance of that part of the theory being strictly true; for in taking a mean of the six examples of the Doric order, the supports are to the weights as 1 : 1·16, in the five of the Ionic order as 1 : 1·05, and in the four of the Corinthian order as 1 : 1·04: a coincidence so remarkable, that it must be attributed to something more than accident, and deserves much more extended consideration than it has hitherto received.

	Order.	Number of Columns.	Supports.	Weights.	Voids.
Temple of Jupiter Nemæus	Doric	6	1·00	0·79	1·03
Parthenon	———	8	1·00	1·07	1·04
Temple of Bassæ	———	6	1·00	1·14	1·16
Temple of Minerva at Sunium	———	6	1·00	1·40	1·17
Temple of Theseus at Athens	———	6	1·00	1·13	1·21
Temple of Jupiter Panhellenius	———	6	1·00	1·45	1·36
Temple of Erectheus	Ionic	6	1·00	0·89	1·24
Temple of Fortuna Virilis	———	4	1·00	1·15	1·71
Temple on the Ilyssus	———	4	1·00	0·96	1·72
Temple of Bacchus at Teos	———	8	1·00	1·35	2·05
Temple of Minerva Polias	———	4	1·00	1·01	2·18
Portico of Septimius Severus	Corinthian	6	1·00	0·93	1·37
Maison Carrée	———	6	1·00	0·93	1·58
Temple at Jackly	———	6	1·00	0·90	1·62
Pantheon	———	8	1·00	1·43	1·84

Short as this sketch is intended to be, it must not be closed without adverting to a curious fact connected with it, viz. the area of the points of support for the edifice which such an arrangement affords. In *fig.* 6, the hatched squares represent the quarter piers or columns in a series of intercolumniations every way, such intercolumniations being 2 diameters or 4 semi-diameters; these added to the 2 quarter piers will make 6, whose square 36, therefore, is the area to be covered with the weight, the 4 quarter piers or columns = 4, hence the points of support are $\frac{4}{36}$ of the area = 0·111. Now in twenty-five of the principal buildings in Europe the ratio is 0·168 on the mean, differing only 0·057 from the result here given; but if we take the subjoined buildings, the mean will be found to differ much less, viz.—

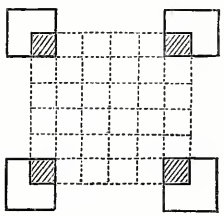


Fig. 6.

Temple of Peace	0·127
S. Paolo fuori le Murà . . .	0·118
S. Sabino	0·100
S. Filippo Neri Naples . .	0·129
	0·474
Mean =	0·118

P.S. *By* Mr. Cresy, *addressed to* Mr. Gwilt.

" Thinking my calculations or views upon this subject may correspond with " yours, and serve to corroborate, or if you have not tested the Pantheon, add " an example to what you have.

" An hexastyle portico, including its entablature and pediment, has its " masses exactly equal to its voids. The columns taken by themselves, and " without any portion of what lies upon them, are equal to one-half the voids; " so that the columns and entablature are equal in quantity.

" The portico of the Pantheon squared in mass contains 7194 superficial " feet, the voids 3512, so that an octastyle temple as well as an hexastyle " temple are established upon the same principle, so curiously that no one would " credit it. To proof:—

" Length of the frieze, 109 feet.

" Heights of the columns . .	46
" Heights of the entablature .	10
" Heights of the half pediment .	10
	$66 \times 109 = 7194$ sup. feet.
" Area of the intercolumniations . . .	3512 sup. feet, or nearly half.

" You will observe I have rejected inches and decimals, and call the entabla- " ture under the pediment 10 feet in height, and the pediment 20, without its " raking cornice, the area of which equals that of the entablature. So the " entablature, the pediment, and the columns, have masses nearly equal, or " divide the 3512 sup. feet between them, or nearly so."

LITHOLOGY;

OR, OBSERVATIONS ON STONE USED FOR BUILDING.

BY C. H. SMITH.

Read at the Ordinary Meetings of the Royal Institute of British Architects, held Monday, 17th of February, and Monday, 2nd March, 1840.

Part I.—Treating chiefly of the Sandstones.

WHOEVER has travelled extensively in Great Britain, for the purpose of examining architectural works of the present and past ages, cannot be otherwise than surprised at the remarkable difference in the condition and durability of the stone. Many beautiful buildings of recent date are in a worse state of external decay than some which have borne the vicissitudes of summer and winter during six or seven centuries. To discover the causes of such decay, and the means of avoiding the evil in future, may appear to be an investigation of some difficulty; especially if we consider the immense variety of stones used for building in this country, each composed of various elementary substances, and in very different proportional quantities; yet, although we may not arrive at a perfect knowledge of the facts, some advantages may be derived from the attempt, such as suggesting inquiries, and giving interest to an important and heretofore unexplored subject, or generalizing and arranging sound practical observations, so as to induce others to take it up. Thus, by a series of well-directed experiments, founded on extensive research amidst old buildings, certain conclusions may probably be inferred, which may ultimately be established on what approaches to scientific evidence.

Whoever expects to find a stone that will stand from century to century, deriding alike the frigid rains and scorching solar rays, without need of reparation, will indeed search for "the philosopher's stone." There is scarcely a

substance, which, after having been exposed to the action of the atmosphere for a considerable time, does not exhibit proofs of "weathering;" it may even be observed on the most densely compacted siliceous rocks. The fullest extent of this inquiry can only be to elucidate relative duration, and comparative labour of appropriation to useful or ornamental purposes.

By examining the various productions of nature, we find evident proofs of her industry in all ages; changes have been going on, from the remotest antiquity to the present time, on every substance that comes within our observation. All the actual combinations of matter have had a former existence in some other state. Nothing exists in nature but what is likely to change its condition and manner of being. No material is so durable as always to retain its present appearance, for the most solid and compact bodies have not such a degree of impenetrability, and so close a union of the parts which compose them, as to be exempted from ultimate dissolution. Even in the great globe which we inhabit, nothing is more evident to geologists than a perpetual series of alterations; there can be discovered no vestige of a beginning, no prospect of an end.

In some bodies these changes are not so frequent and remarkable as in others, though equally certain at a more distant period. The venerable remains of Egyptian splendour, many of them executed in the hardest granite, between three and four thousand years since, exhibit large portions of exfoliation and gradual decay, thereby following the primitive, immutable, and universal order of causes and effects, which the Creator has assigned to his productions, namely, that all objects possess the materials of which they are composed only for a limited time, during which some powerful agent effects their decomposition, and sets the elementary particles at liberty again to form other equally perfect combinations. Thus, by divine and unerring laws, order is restored amidst apparent confusion.

During the last ten or fifteen years, the various improvements in arts, sciences, and manufactures have been carried to an extent unknown in any former period; and these changes have frequently given rise, either directly or indirectly, to ideas which have ultimately led to results of great public utility. With this sort of universal advancement the constructive department of architecture seems now to be somewhat following in the popular current.

For a long period, the most refined taste in elegant architecture was extensively practised throughout this country upon scientific principles, which, if ever equalled, have most assuredly never been surpassed; yet the quality of the stone employed seems rarely to have been considered further than for the

facility with which it might be wrought by workmen. Relics of long-departed grandeur, either of the ecclesiastical or baronial order, abound in most parts of the kingdom; nearly all these beautiful works of our ancestors are constructed with stone from the immediate neighbourhood of such buildings, apparently without any regard to colour, strata, or durability; and hence we frequently find stones of very different tints indiscriminately placed together in the same elevation, some extremely perfect, others in a very mouldering condition [1].

It is easy to conceive the difficulties that would arise in obtaining a large quantity of so ponderous a substance as stone from the distance of only a few miles; and, in situations remote from the sea or from navigable rivers, at a period when few good roads were available, and canals were neither known nor thought of, the transporting a supply of stone for an extensive edifice would necessarily be attended with vast labour, and, in many cases, would appear to be an insurmountable difficulty.

In nearly all the old English buildings, we rarely find a stone larger than might be conveniently moved or carried by two or three men; and there is good reason to believe, that notwithstanding the quarry might be but a few miles distant, probably over hills and dales, the most practicable mode of conveying the stone to the building was by pack horses, of either single or double burden [2]. While these numerous disadvantages existed, we need not be surprised to find materials of an inferior quality used, for the sake of convenience, in the construction of all kinds of edifices, and frequently even in those of a magnificent character.

No doubt these circumstances originated sometimes from necessity, at other times through ignorance; but an attentive examination of various old buildings will soon convince us that economy was formerly, as it too often is now, the ruling power; far more so than a casual observer would imagine. Even at one of our principal seminaries of learning, there is a remarkable instance of ostentatious display, executed in the most fragile stone that I have ever beheld.

[1] Whitby Abbey is built of sandstone, varying in colour from white to a dark umber brown, carelessly mingled, and presenting a motley appearance. In all cases the brown stone is more decomposed than the white.

Bristol Cathedral is built of red sandstone and yellow limestone, strangely intermingled. The sandstone appears to be invariably more decomposed than the limestone.

King's College Chapel at Cambridge is built partly of white magnesian limestone, from Huddlestone, in Yorkshire, and a brown shelly oolite, from Weldon, in Northamptonshire; evidently without distinction, or study to suit the architectural arrangement. The magnesian limestone is throughout much more dilapidated than the shelly oolite.

[2] A kind of sedan or chairman's horse, the poles of which were slung in the stirrups, and the weight borne by two horses: a mode adopted by our forefathers for carrying heavy goods on bad roads.

Nearly all the colleges, halls, churches, and other public buildings at Oxford, present elegant architectural designs, and, with few exceptions, they are all now in the most ridiculous looking state of decomposition. Here we have an evident proof, that those who had the direction of the works knew they were using a bad material; because, in many examples, the greater part of each structure is executed in Heddington stone, which is procured from quarries about a mile or two from the University, and may be worked with great facility; but wherever it has been used the result is deplorable in the extreme, every exposed surface appearing affected by what in medical language would be termed "a cutaneous disease," peeling off and hanging like paper or rags. But the more exposed parts of the same buildings, such as base mouldings or cornices, are formed of a very superior stone from the Taynton quarries, distant about twelve miles land carriage, which increases very considerably the expense of such material: it is therefore rarely introduced. But, notwithstanding the Taynton stone has always been put in situations most likely to be affected by the weather, it almost invariably appears to be in an excellent state of preservation, and fit to be again used without fresh working the surface, in all cases where the buildings have been restored or rebuilt according to the original design.

I am not prepared to say whether Caen stone was used in this country before the Norman invasion; but it appears to have been considerably, though far from generally, used for ornamental architecture in the south of England, from the Conquest to the time of Henry the Eighth. It does not seem to possess any advantages over various stones of the same character, the produce of our own country. Many qualities of stone are to be found in the same district, and frequently even in the same quarry. This remark is particularly applicable to the Caen stone; the proprietors sell the coarse-grained, inferior kind, fit only for plain buildings, at probably half the price of such as is suitable for sculptural and ornamental purposes. All these varieties possess different degrees of durability. The central tower of Canterbury Cathedral, St. George's Chapel at Windsor, and Henry the Seventh's Chapel at Westminster, were all built with Caen stone about the same time, between 1472 and 1517; yet the tower of Canterbury, notwithstanding its elevated and exposed situation, is at this time in a much better condition than the generality of structures of that date; and St. George's Chapel is by no means so much dilapidated as that at Westminster before it was restored between 1808 and 1822.

I am inclined to believe that the cause of so much difference in durability arises much more from the different qualities of the same description of stone

than from any local circumstances; because the north front of Westminster Hall, finished about 1400, situated in the immediate vicinity of Henry the Seventh's Chapel, with an aspect equally unfavourable, was not, before its restoration eighteen years ago, so much dilapidated as the latter building, although erected one hundred years earlier.

In London, the demand for stone has at all times been considerable. During the long period that the chief supplies for highly decorated buildings were imported from Normandy, various circumstances must have occurred to delay the arrival of cargoes. Political disputes between the two countries most probably occasioned the importation of Caen stone to be altogether prohibited. At such intervals, the rocks nearest to the metropolis would necessarily be made available; and accordingly in almost all old buildings we find occasionally introduced large portions of stone from the vicinity of Ryegate and Godstone, known by the various names of Ryegate stone, Gatton stone, Merstham stone, fire stone, and more commonly as hearth stone. This material must always have been expensive in London, on account of the distance to fetch it, being twenty miles land carriage. It may be very expeditiously worked, nevertheless it ought not to be used for external purposes, as I do not recollect an instance where it has been exposed to the atmosphere for twenty or thirty years without the surface having mouldered away in small flakes, so as ultimately to obliterate all architectural details. The greater part of Westminster Abbey was formerly built with stone brought from quarries at Godstone, from which circumstance that village is said to have derived its name. Sir Christopher Wren, in alluding to the repairs of the abbey, describes the stonework as having mouldered away four inches deep from the original surface. He repaired the parts most decayed with stone "brought down the river from near Burford, in Oxfordshire[3]." A specimen of this reparation may be seen on the exterior of the north transept, and on the north side of the choir, as far as Henry the Seventh's Chapel. Ryegate stone was not entirely out of use in the time of James the First, for Inigo Jones introduced it in part of the front of Whitehall[4].

While both Caen and Ryegate stones were in general use for ornamental

[3] Parentalia, page 299. The principal quarries near Burford are the Taynton and the Windrush. The latter contains stone most like Sir Christopher's restorations.

[4] The festoons of fruit, &c. on a line with the capitals of the upper columns were originally carved in this stone, and so much decomposed before the repairs in 1826, that they were taken down, and new ones, executed in Portland stone, were substituted. A specimen of this stone may be seen, in a deplorable state of decay, forming the basement story of some of the government offices behind Whitehall Chapel. These buildings are remains of the old Palace of Whitehall, and contain some curious groined ceilings well deserving the notice of an antiquary.

architecture, large quantities of hard gray limestone, generally known by the name of Kentish rag, were brought to London, by water, from the neighbourhood of Maidstone, and extensively used for ruder purposes. The basement, or plinth next the ground, of Henry the Seventh's Chapel, at Westminster, is formed of this stone, and large masses of wall, of the same material, have been found in digging the foundations for the new Houses of Parliament.

About this time, or soon after the year 1600, Portland became the general stone used for superior buildings in London and the south of England. But as I intend to devote more time to that material than to any other, I propose leaving it for the present, and now proceed to describe the sandstones generally.

It is not my intention to attempt a description of the various qualities and adaptations of granite, further than to allude briefly to the cause and result of its decomposition.

In the order of creation, granite is decidedly among the oldest formations; it may be considered as the father of most other rocks, especially of the numerous varieties of sandstone. Granite is generally composed of coarse grains or crystals, of so hard and refractory a nature as to render it only suitable for those bold massive structures which have scarcely any embellishment. It may be considered good and durable in proportion to the fineness of the component parts, and especially in proportion to the abundance of quartz and scarcity of felspar. In Cornwall and part of Devonshire, the granite is remarkable for the superabundance of well-defined and large crystals of white felspar which it contains; and this is the reason why the granite from those countries is less durable than the Aberdeen or Guernsey, in which there is comparatively little felspar in proportion to the quantity of quartz and mica. At the Earl of Morley's quarries, in the vicinity of Prince Town, Dartmoor, the granite is more or less decomposed to the depth of fifty or sixty feet; and this surface granite has been used in almost all cases, because it may be obtained at the cheapest rate; the result is, that in all buildings which have stood for a number of years, such as the Dartmoor prison, each block of granite has become a porous mass, absorbing moisture continually, rusting the iron bars employed in combination with it, and rendering the cells so damp that they can only be used by covering the walls both inside and outside with Roman cement and tiles. This defect is observable in all the granite which is not quarried from a depth below the influence of decomposition.

Felspar is a compound body, in which certain alkaline substances always form a predominant ingredient, rendering it extremely liable to decomposition,

especially if it be exposed to the atmosphere in a damp or wet situation. While this process is going on, the lustre of the felspar is gradually diminished, its colour is altered, its hardness and cohesion destroyed, until at length the mass is completely changed into some kind of clay, fit for pottery. Another reason why the granite of Cornwall decomposes so readily is, that its felspar contains an unusually large proportion of alkaline matter, which always has a great affinity for moisture. A few miles north of Plymouth, the surface of the country, over hundreds of acres, is covered with decomposed felspar, in a state resembling flour, produced from this description of granite; it is purified by passing streams of water over it, and when prepared and baked, as usual in the manufacture of china, it forms a beautiful porcelain. Specimens, showing the natural and artificial gradations of the decomposing granite, felspar, clay, and the porcelain prepared from it, may be seen at the Museum of Economic Geology, in Craig's Court, Charing Cross.

In granite rocks felspar is generally more abundant than either quartz or mica; consequently if it be removed by the means which I have described, a rapid disintegration of the remaining portions must readily take place[5]; leaving the silicious sand, mixed with certain quantities of mica, entirely separated from the clay and alkaline salts of the decomposed felspar. If sufficient time be allowed, the sand will ultimately become indurated into compact sandstone. This process of decomposition and partial induration must have gone on to an enormous extent, and continued through a vast period of ages, in order to have produced all the sandstone rocks which now constitute so large a portion of the earth's surface.

All rocks appear to have been formed either entirely under water, or by frequent alternations of wet and dry. Sandstones frequently present a laminated structure, as if by the overflow and recession of a tide, which constantly left a sandy sediment, with minute plates of mica from the decomposed granite. These plates, being thin compared with their size, are almost invariably found

[5] The southern or river front of Somerset House is remarkable for being constructed with granite and two kinds of Portland stone: from the foundation to the commencement of the arched openings under the terrace, a height of about ten feet, is composed of granite, which already exhibits abundant proofs of disintegration; the entire rusticated basement above the granite, up to the cornice under the balustrade of the terrace, is of Portland stone, in a most capital state of preservation. A conspicuous line of demarcation may be seen along the cornice of the basement; all above which, or from the level of the terrace to the top of the building, is constructed with Portland stone of so inferior a quality, that it is in a perishable state and fast mouldering away. Thus a fresh surface of stone, exhibiting its natural colour, is always exposed to view, whilst the lower portion of the same edifice, being constructed with durable Portland stone, retains its original surface with a colouring of soot and dirt, the effect of a London atmosphere.

with their flat surfaces parallel to the lamination; thus indicating most distinctly the bed-way of a stone, by their presenting a spangled or glittering appearance when viewed in a direction to reflect the light; an effect not to be met with on viewing a surface across the strata. The extreme tenuity and elasticity of the plates, into which mica may be divided with the greatest ease, and the situation of the plates, generally parallel to each other, will somewhat account for the readiness with which micaceous stones peel off in thin sheets. The material so extensively used in London especially for foot pavements, popularly known by the general term "Yorkshire stone," will serve to illustrate these remarks[6].

If a stone that is evidently laminated be placed in an exposed situation, with the planes of lamination parallel to the outward surface of a building, it will exfoliate or decompose in flakes according to the thickness of the laminæ; whereas if the same stone were placed so that the planes of lamination be horizontal, that is, most commonly upon its natural bed, the amount of decomposition will be comparatively immaterial.

Some of the sandstones are irregularly laminated, presenting an appearance across the strata of a number of short black lines, arising from small quantities of carbonaceous matter being interspersed in beds, often parallel to each other, as in Craigleith bed rock, but occasionally, as if formed by a succession of minute undulations similar to rippled markings of agitated shallow water upon sand. The stone from Garscube or President quarry, near Glasgow, is of this description.

Many sandstones are composed of small pebbles, varying considerably in appearance, and often essentially different in their elementary character. These are coarsely conglomerated together so as to form a sort of pudding stone or indurated gravel, of which Bramley Fall, especially the coarse-grained variety, is a good example. If these various substances be exposed to the same causes of decomposition, they will resist them unequally; those parts of the stone

[6] It is not generally known, except among masons and builders, that there are numerous qualities of stone, all sold by the London merchants, under the extremely vague term of "Yorkshire stone," differing essentially in strength when laid horizontally for foundations or lintels, and in wear when used for steps or paving. Hence it may be useful to state, that such stone as is usually denominated "self-faced," is procured from the uppermost strata in the quarry, and is therefore more "weathered," and not near so strong or so durable as that which is obtained from a greater depth below the surface, and which is generally converted into "quarry-worked" or "tooled-faced stones." If "rubbed York steps" are specified to be used in a building, under an idea of their being the same quality of stone as if described to be "quarry-worked or tooled," unless strictly enforced, the builders will saw them out of "soft York blocks," which, as the name implies, is much softer and will not wear near so long as the stone usually wrought at the quarry into "tooled steps." The hardest, most durable, and strongest York stone is generally of either a bluish grey or comparatively of a pale brown colour.

which decompose most readily being removed, leave the durable portions exposed, so as to be more easily affected by mechanical forces, such as the freezing and expanding of water after being absorbed by the pores of the stone, occasioning a disruption of the external particles. A constant succession of these chemical and mechanical operations will disintegrate a mass of stone, composed of various substances, in much less time than if the same bulk were formed of one uniform homogeneous material, even if that one material were the most decomposable portion of the conglomerate to which I have just alluded.

After having examined the component parts of a stone, the next consideration must be the condition of those parts to form the aggregate. In all specimens of genuine sandstone, the grains are infinitely more durable than the cement which unites them; and in some cases, notwithstanding the cement is of the best quality, it may be so scantily supplied that the grains are scarcely attached to each other, consequently such stone must be extremely friable, and will suffer from all kinds of mechanical forces. The greatest portion of the mass of all sandstone is made up of quartz or silicious grains. If the substance that cements the grains together be also silicious, the stone will most probably be very durable;[7] but we frequently find silicious grains cemented with argillaceous, calcareous, ferruginous, or other matters, each of which has more or less affinity for the silica, and, of course, the grains are more or less firmly attached to each other. Those cements which partake most of the character

[7] The liver rock of the Craigleith quarries appears to be very nearly a perfect example of sandstone. According to Professor Daniell's analyses, in the Report on the Selection of Stone for the New Houses of Parliament, it is composed of more than 98 per cent. of silica, therefore probably wholly free from foreign matter. The grains are beautifully crystalline, united with abundance of silicious cement.

Notwithstanding all the discoveries and improvements which have been made in chemical science, we are still unacquainted with the means of dissolving silica in water or other fluid, so as to imitate nature, or to show how silicious earth is produced in the animal, vegetable, and mineral kingdoms. The presence of silica, completely in solution, may be detected in various mineral springs, especially if they are naturally hot or tepid, as in those at Bath, which is the more remarkable, because the Bath waters contain no alkali, nor any material known to contribute to its solution. The Geysers, or boiling fountains in Iceland, contain nine or ten grains of silica in every hundred cubic inches of water, from whence solid silicious matter is copiously deposited about the mouth of each fountain. A small quantity of silica is also to be met with in the hair, horns, and feathers of animals; and it is secreted in larger quantities on the wings or hard shiny external casing of the numerous tribes of beetles; it is likewise deposited abundantly round the outside of cane, bamboo, straw, and all the larger kinds of grasses. These facts are constantly operating in the beautiful laboratory of nature, but they, like many others, are inexplicable with our present knowledge. The elementary substances which form either chert, flint, quartz, or sandstone, are produced perfectly in solution, but we are ignorant of the means; neither can we discover, by any of the ordinary processes of nature, a mode of dissolving the individual grains which compose silicious rocks, their decomposition being usually effected by disintegration, or separation of the grains from each other by mechanical forces, assisted by some chemical agency.

of iron or clay are most likely to separate from the grains of quartz; consequently a sandstone thus compounded will in all probability soon yield to atmospheric influences, because the oxygen of the atmosphere produces considerable alteration in stone containing much iron, under which circumstance it is generally reduced from a hard and refractory to a soft and crumbling substance[8]. If the component parts of a stone be silicious, with a calcareous cement, there is good reason to believe that such a substance will stand the weather tolerably well, for it may be considered the natural product, of which human ingenuity has, from a very remote period, successfully formed an imitation in the commonest of all building materials, mortar[9].

A defect to which all the sandstones are liable is, that a portion of uncrystallized carbonaceous, ochrey, or earthy powder, sometimes nearly fills the interstices between the crystals, occasionally forming what are called "clay balls," and often lying between the laminations. These are always injurious to the durability of a stone, especially if they amount to any considerable quantity.

In sandstone quarries, except the uppermost strata, there is very seldom any material difference between the numerous beds, as regards their qualities of withstanding the weather. The quarries belonging to the Duke of Devonshire, by the side of the river Derwent, in Derbyshire, have a depth of workable stone of at least forty feet, in eight or ten beds, all as near as possible of the same quality. The numerous quarries in the neighbourhood of Leeds and Huddersfield have many beds in a thickness of about fifty feet, some of them coarser in grain than the rest, but no essential difference in durability has been noticed. The same remarks will apply to the sandstone quarries about Dundee, Edinburgh, and Glasgow; especially to the celebrated quarry at Craigleith, which was originally a hill about one hundred feet high, but where there is now an excavation not less that one hundred feet below the surface of the ground; and the proprietors have ascertained, by boring, that the same kind of stone is to be found considerably deeper. Here then we have an instance of between two and three hundred feet of stone, in about two hundred beds, all of the same quality. Lenticular masses of liver rock are occasionally found, but their occurrence is quite uncertain. No difference in durability has been discovered in any of the

[8] Pontefract Castle, now in the worst state of decay, is built of a dark brown ferruginous sandstone. Many of the stones are so soft and fragile, that they may be abraded with the naked finger. Most of the stone in the neighbourhood of Tunbridge Wells is extremely ferruginous, and so slightly cemented together, that a lump may be crumbled to atoms in the hand.

[9] The choir of Southwell Church, Nottinghamshire, built in the twelfth century, with Mansfield stone, which is of this description, is generally in good condition.

beds or masses, except that the bed rock will flake off if placed vertically in an exposed situation, a defect common to all beddy stones, whereas the liver rock is equally durable, or nearly so, in whatever position it may be fixed.

There is one peculiarity in the sandstones which I think highly deserving notice, and that is, the labour of converting them to useful, or more especially to decorative purposes. Architectural ornaments, whether mouldings, carvings, or other decorations required to be well executed, particularly if on a small scale, will unavoidably occupy much time if carved in sandstone, on account of the nature of the material, which is so destructive to edge tools. In confirmation of this assertion, it is necessary to remark, that the only material for sharpening edge tools is sandstone, either as a hone, or turkey stone used by joiners and cabinet makers, grind stone, scythe stone, and many more, all of which are of a sharp sandy texture. Therefore it is easy to conceive that the same kind of stone which is experimentally found to sharpen tools most expeditiously, will also be the readiest to destroy their cutting edge, and thereby not only retard the progress of the workman, but occupy his time in frequently resharpening them. Quartz is one of the hardest substances in nature—much harder than steel; therefore instead of the chisels cutting the stone, the stone cuts the chisels, and a portion of the steel is left upon the stone after every blow. The actual effect of the tools on sandstone is to force the grains to separate from each other by concussion, for it is impossible to cut a hard substance with a comparatively soft instrument[10].

Stone that is to be used at a distance from the quarry cannot be profitably applied to architectural works, unless capable of being sawed with facility; as experience teaches that it is cheaper to have blocks larger than necessary, and run the risk of damage in loading and unloading, than to take more time and care to prevent such mischief; the value of the cubic contents of the stone that is thus wasted being less than that of the time which would be occupied in packing it with greater care. If the blocks can be reduced to the requisite dimensions by sawing at a moderate expense, the saving will be considerable, as the sawed faces are nearly fit to pass as finished for "plain work," and the surplus pieces serve for ashlar, paving, &c. But should the expense of sawing be so great as to render it unadvisable to proceed in this way, then the blocks must be roughed out at the quarry, and left a few inches larger than required, on account of the damage likely to occur on board ship, and in the various

[10] While working sandstone by twilight or faint candlelight, considerable flashes of light may be seen, somewhat similar to those produced from a flint and steel, whenever the stone is struck with a steel tool, an effect peculiar to the sandstones only.

removals to their final destination. The plain surfaces must then be worked by manual labour, and the surplus stone which is chipped off will be merely rubbish, after having paid for its freight, cranage, cartage, and many other expenses. The sandstones are all expensive to saw, on account of the hardness of their component parts, and the excessive wear and tear of the saw-plate; this I have ascertained from my own experience. The Craigleith stone, which deserves to be classed among the best of the sandstones, costs nearly four times as much to saw as Portland stone[11].

It is important in many respects whether the component parts of sandstone be fine or coarse. Some kinds are composed of such large particles, as to be distinctly visible to the naked eye at the distance of several feet. The coarsest of Bramley Fall, and of other mill-stone grits from the vicinity of Leeds, are examples of this description. Other varieties of sandstone are so finely grained, as to require a microscope of considerable power to distinguish their structure. Should two such specimens be exposed to precisely the same atmospheric influences, and all other conditions be equal, the coarse grained would certainly be the first to decompose. Among the numerous sandstone buildings in this country, those which have been constructed with a fine-grained stone are usually in the best state of preservation; and it may generally be considered as a sort of rule, that the same description of work can be performed in less time if the stone be fine-grained than if it be coarse.

Particular cases may come under an architect's consideration, wherein the specific gravity or weight of stone is of serious importance, such as landing places or steps, occasionally under water, where there may be a rapid current, or in other situations, subject to the influence of powerful waves, especially of sea water; such circumstances will require that a heavy stone should be used, because all bodies immerged are reduced in weight precisely equal to that of the bulk of water which they displace. The lightest stone I have ever found is from Gatton, in Surrey, weighing one hundred and three pounds to the cubic foot. Now if similar stone were used in water, it would be reduced sixty-three pounds (the weight of a cubic foot of water); therefore it would be like building on land with a material weighing only about forty pounds to the foot. The

[11] A house faced with Craigleith stone may be seen in London, adjoining the garden of T. H. Hope, Esq. in Queen Ann Street, facing Chandos Street, Cavendish Square. It was designed and built by the celebrated architects of the Adelphi, Robert and James Adam, immediately after their leaving Edinburgh to practice in London. Although it is upwards of eighty years since this house was erected, scarcely any symptoms of decomposition appear. The front has lately been painted, not for the sake of preservation, but because it was so thoroughly blackened with the soot of the metropolis.

heaviest building stones that have yet come within my notice are the dark grey varieties of sandstone, from the vicinity of Swansea, Glamorganshire; Abercarne, Monmouthshire; the Forest of Dean, Gloucestershire; and the neighbourhood of Dundee: some of which are even heavier than granite, and I think quite as durable, weighing upwards of one hundred and seventy pounds per cubic foot. Hence you will immediately perceive that such stones are peculiarly well adapted for docks, harbours, breakwaters to bridges, and all other purposes where the violent commotion of water is to be contended with. In situations constantly or alternately under sea water, sandstone is preferable to limestone, because it is not so liable to be perforated by the saxicava rugosa, the pholas, or other boring mollusca, which frequently honeycomb calcareous stones within their reach to the depth of several inches.

It is not very likely that a well-developed oolite would be taken for a sandstone, but I think it extremely probable that a casual observer might mistake some of the highly crystalline limestones for sandstones, and a very fine-grained sandstone might just as likely be taken for a limestone. The more scientific method of detecting the difference is to test them with an acid; diluted muriatic acid is perhaps the best; but this is not a very agreeable fluid to carry in the pocket, and not always to be obtained conveniently; and if it were, some of the beautifully crystallized magnesian limestones are at first so amazingly slow in their progress of effervescence, that an inexperienced person might decide erroneously without waiting for the actual result. The method most convenient on all occasions, and which I am inclined to believe will rarely if ever lead to false conclusions, is to try if the specimen will scratch glass with a slight pressure of the hand; common crown glass is better for this purpose than any other; and if it makes a mark that cannot be wiped off with the finger, there is no doubt of the sample being a sandstone, composed chiefly of quartz or silicious grains. There are, I admit, other substances which will scratch glass, such as diamonds, rubies, and most of the precious stones, but these are never found in enormous masses. Chert or flint will also do the same, but no one would test such materials under an impression that they might be sandstone, their appearance alone being a sufficient proof. The method I have proposed is only intended for such stones as, by their resemblance to others, might probably lead to erroneous conclusions.

Part II.—Treating chiefly of the Oolites.

Few branches of physical science present a more extensive field for the imagination to range in, or a more complete series of well-established facts, than that which relates to calcareous substances. Limestone is one of the most abundant materials in the creation. Geologists have estimated it as occupying probably an eighth part of the external crust of the globe; and it appears distributed throughout the world proportionably to its general utility in the animal economy.

From the chemical resemblance of all limestone and marble to the material constituting fish-shells and corals in general; from the well-known rapid accumulation of the latter, and from the prodigious beds and districts of the remains of crustaceous animals uniformly occurring in the contexture of many varieties of stone, it has with good reason been conjectured that marble, limestone, and all other indurated calcareous rocks, derive their origin from the animated productions of the waters, ultimately diversified by local circumstances, and differently modified by combinations with which we are at present but little acquainted. To an architect it is a question of little importance whence or under what conditions the limestones originated. To a contemplative mind such an investigation must produce the most sublime reflections on Almighty power; but such notions must now be dismissed, in order to consider, not what limestone has been, but what is its present state, and what its condition is likely to be, if exposed to the weather for a few centuries.

The general term "limestone" must be understood to include many varieties, such as those which are composed almost entirely of shells, others named oolites, magnesian limestones, and several of excellent quality that form a sort of connecting link between those of a more definite kind. The purest and most compact limestone may be defined as a transparent, colourless, solid substance. Iceland, or double refracting spar, is probably the purest carbonate of lime; white marble is also extremely pure, the separate crystals of which are nearly transparent. But the limestone generally used for masonry is more porous, frequently quite opaque, and specimens may be found of many different colours. On examining the internal structure of calcareous rocks, they will be found to be adorned with patterns of variegated hues and forms. Shells may be observed in one, veins in another, corals and encrinital cylinders in others, and some in

which no particular figure can be discovered; and, notwithstanding they differ so much in appearance, yet the very materials that nature applied to form such apparently opposite creations are almost identical: the whitest chalk and the blackest marble, the softest Bath stone and the hardest Purbeck, are all formed of very nearly the same materials, scarcely differing, except in the manner in which they are developed, or in the nature and extent of their duration.

If a fine-grained limestone has so considerable a degree of hardness that it will take a good polish, it receives the pompous name of "marble," although it may possess no chemical qualities but such as are common to all the calcareous earths.

The extremely fine-grained kinds of limestone often contain in their composition argillaceous earth, which renders them unfit for external work, especially if the proportional amount is great. Totternhoe stone, from the environs of Dunstable, is the softest and finest grained stone I have ever seen used for architectural works; all those richly carved altar screens, shrines, and chapels, in St. Alban's Abbey, are made of this material; it contains at least thirty per cent. of clay in its composition, and has failed in most instances where it has been exposed to the weather, even where it has been used for ashlar, protected with a more durable stone for cornices and dressings. A newly-fractured dry specimen gives out a peculiarly earthy odour immediately after being breathed upon; but a more certain method of detecting the clay is to dissolve some fragments in diluted muriatic acid, which will hold the lime in solution, leaving the clay at the bottom of the vessel; if this be washed to get rid of the acid, it may be collected, dried, and, after being made red hot in a common fire, it will become precisely like a piece of brick or tile.

Some of the shelly varieties of limestone are extremely durable, although of too coarse a texture for small ornaments. The formation appears to have been a vast quantity of shells, rarely exceeding two or three species, most of them broken or pulverised, and apparently water-worn. In process of time the mass became indurated and cemented together with carbonate of lime from the decomposed shells. In this state, when applied to architectural works, the shells which have remained unbroken, and the largest fragments, seem to exercise a sort of protective influence over the exposed surface of the stone. If the softer parts of a shelly stone have decomposed in the first hundred years so much as to leave the shells projecting before the general surface, to the extent perhaps of an eighth of an inch, we must not calculate that decay will continue progressing at the same rate, for the numerous projections prevent mechanical violence, and preserve the more fragile parts of the stone in a variety of ways;

so that probably in the second hundred years decomposition will not be more than a sixteenth of an inch, and less and less every year. The best kinds of shelly limestone are from Barnack, near Stamford; Taynton, near Burford; Ham Hill, near Yeovil; Weldon in the Wood, Northamptonshire; and Grove quarries at Portland. All these are only varieties of the oolitic rocks; in most of them the ova may be distinctly observed in the spaces between the shells.

The oolitic rocks traverse England from the extremity of Yorkshire to the coast of Dorsetshire, in many places affording prodigious quantities of excellent stone for building; but variations of structure, hardness, and durability are found in different quarries, tending to show the changeable nature of the subdivisions, even in short distances, throughout the entire district, which extends nearly three hundred miles. At an early period it is but reasonable to suppose that the ova or oolitic grains were loosely deposited in prodigious heaps at distinct and distant periods of time, which will account for the several beds or strata. It is with the oolites as with most other stones, that the goodness or power to resist decomposition depends chiefly upon the quantity and quality of the cementing substance by which the particles adhere to each other. The cement that makes the globules into a mass, is formed of the same elements as the globules themselves, but more crystalline; it is, in fact, the decomposition of some of the superincumbent mass, saturating and crystallizing throughout the beds beneath.

As the cement is of primary importance to the duration of a stone, I think it advisable to give a short account of its formation or physical properties. Water, even in its simplest state, may be considered to act as a solvent to most things; but when it contains acid, its power of dissolving calcareous substances is considerably augmented. Many waters are impregnated with carbonic acid, obtained partly from the atmosphere, and frequently from subterranean sources. If they contain a superabundance of carbonic acid, they will rapidly decompose limestone, and carry the atoms thus sustained in solution until a certain quantity of the acid, in a gaseous state, has evaporated, when the atoms of limestone will again solidify in crystals, and perhaps assume a totally different character. If this ingenious process of nature be carried on for a great length of time, over a considerable thickness of loose calcareous matter, the probability is that the water, thus charged with lime and carbonic acid, will saturate the more porous parts, and thus ultimately form a well-cemented and compact limestone, of what was originally a congeries of loose ova or grains. Where these waters trickle through a vaulted roof, and pervade the walls of those natural caverns in which limestone strata abound, they stud the sides with

an infinity of brilliant crystalline deposites, or produce pendant stalactites, that hang from the ceiling in a thousand fantastic forms.

Carbonic acid is probably generated by nature more abundantly in Italy than in any other country. Most of the waters which flow from the Apennines are highly impregnated with it, owing most likely to subterranean fire acting upon the calcareous rocks of which the Apennines are composed. Such waters, charged with carbonic acid, will, as already described, under different circumstances, at one time dissolve and afterward deposit calcareous matter. In Italy these aqueous depositions have always produced enormous quantities of durable building stone, known by the various names of Travertine, Marmor Tiburtinum, calcareous tufa, &c. Some of the Italian lakes and streams are so completely saturated with the materials which form limestone, that if a stick be thrown in, a few hours is sufficient to give it an incrustation of this substance. Sir Humphry Davy, in describing the Lacus Albula, or Lake of the Solfatara, which discharges itself into the Anio or Teverone below Tivoli, says, "In May, 18—, I fixed a stick on a mass of travertine covered by the water, and I examined it in the beginning of the April following, for the purpose of determining the nature of the depositions. The water was lower at this time, yet I had some difficulty by means of a sharp-pointed hammer in breaking the mass which adhered to the bottom of the stick; it was several inches in thickness[11]." The county of Derbyshire furnishes instructive and interesting illustrations of all such peculiarities in the action of carbonated water upon limestone; and the well-known "petrifying spring" at Matlock presents an excellent example. But such aqueous depositions almost always occur where carbonic acid and lime are present. Even the stony concrescence, usually denominated "fur," which is often secreted upon human teeth, and which is occasioned by lime taken in the water or food meeting with carbonic acid expired from the lungs, is in every respect the same as the travertine with which the Cyclopean walls and the gigantic temples at Pæstum and in Sicily are built. In all cases crystallization is materially assisted by having some solid body for a nucleus, especially if that nucleus be of the same mineralogical character as the solution to be crystallized. Thus it is that the oolitic ova all contain a central speck, sometimes of limestone, very frequently a minute fragment of shell, from which needle-shaped crystals commence.

By a chemical analysis of different specimens of oolite, selected from quarries at a considerable distance from each other, we learn not only that they

[11] Consolations in Travel, or the Last Days of a Philosopher. By Sir Humphry Davy, bart. Page 117.

are all composed of nearly the same elements, but also that the proportional quantities of the elementary substances which form the aggregate of each stone do not materially vary in any of them[12]. The mechanical arrangement of the atoms which form the ova and the cement must, therefore, be examined, to find out the cause of so much difference in durability and the influence of weather which is known by experience to exist among the oolites.

In some stones the ova is so extremely soft as to resemble minute balls of chalk; if these are united with an abundance of well crystallized cement, the stone will in all probability be a durable one, although the ova near the surface will very soon be washed out, leaving an extremely cellular structure, somewhat resembling fine sponge. Stone from the Taynton quarries, near Burford, to which I alluded in my former paper, as having been used in the most exposed parts of the buildings at Oxford, is a good example of a material of this description.

The stone from the Ketton quarries, in Rutlandshire, is a remarkably well developed oolite; the ova of the lowest bed, which is the only bed used for architectural works, has scarcely sufficient cement to hold them together, nevertheless that small quantity is of the best quality; and although this stone is by no means among the most durable, it resists disintegration much better than might be expected from its appearance, which presents a remarkably open and porous texture.

Many quarries of oolite contain upper beds considerably harder than those which lie beneath, arising from the ova being very hard, and the interstices being completely filled with a compact highly crystalline cement. Stone of this description is generally very durable, but frequently unfit for general purposes, because its hardness renders the labour of working it into ornamental archi-

[12] The following analyses of oolites, as given by Professor Daniell, in the Report on the Selection of Stone for building the new Houses of Parliament, will show how nearly the proportional quantities of the component parts in four specimens, possessing very different degrees of durability when exposed to the weather, approach each other. They are chiefly composed of carbonate of lime; the greatest difference does not amount to 3 per cent. of that material, and the Portland contains a small quantity of silica.

	Ancaster.	Bath, Box Quarries.	Portland, Way-croft Quarries.	Ketton.
Silica	.....	.....	1·20	.....
Carbonate of lime	93·59	94·52	95·16	92·17
Carbonate of magnesia	2·90	2·50	1·20	4·10
Iron alumina	·80	1·20	·50	·90
Water and loss	2·71	1·78	1·94	2·83
Bitumen	A trace.	A trace.	A trace.	A trace.

tecture rather expensive. The stratum immediately above the lowest bed, or "freestone," in the Ketton quarries, called by the quarrymen "Ketton rag," may be named as a specimen of such material; and it is worthy of notice for the large quantity of cement between the ova, the interstices being filled up with a hard, beautifully crystalline, transparent cement, which adheres so firmly to the globules, that a fractured surface of the stone presents almost all of them broken; the same rend appears to pass as readily through the ova as through the cement, instead of the entire globules being separated from the cement, and leaving hollow, cup-shaped cavities.

If the ova be soft and chalky, with only a small quantity of cement, and that of a slightly crystalline character, such stone, if exposed to the weather, or to frequent alternations of wet and dry, will very soon begin to moulder away from the most exposed or most projecting parts. Large quantities of such kind of material are brought from the hills in the vicinity of Bath. The principal quarries are at Box, Coombe Down, and Monckton Farleigh. The stone from each of these districts, and even in the same quarry, where there are generally a number of beds lying upon one another, is frequently found to differ, in some of the minor characters, from all the rest; such as being harder, coarser, more or less durable, &c. all of which are indiscriminately sold in the markets under the general name of "Bath stone," and it rarely happens that an architect specifies what kind of Bath stone is to be used. It is always understood that the materials are to be good, or of the best kind; and it unfortunately too often happens that the stone which looks best when fresh from the workman's hand, is frequently of a description most subject to premature decay. If it be left to the mason's choice, he is sure to select the stone that may be most expeditiously worked.

Bath stone has been used almost universally, as a mineral substance for building, in the city of Bath, during a long period. The Abbey Church, which was not finished till after the Reformation, has been in great part restored within the last thirty or forty years. The west front has been richly ornamented, especially with a representation of Jacob's ladder on each tower, reaching from top to bottom, on which many angels were carved in bold relief; these have now mouldered away, till only a few faint traces remain, just sufficient to indicate where they originally were. This building I am inclined to believe is the oldest in existence of Bath stone, and beyond doubt not a very favourable specimen of its durability. The oldest of the modern buildings of similar material in that city, is, I imagine, Queen Square, erected in the beginning of the last century; the houses are ornamented with projecting mouldings, Corinthian

capitals, &c. and certainly they are not much decomposed, considering the time since they were erected.

It has been remarked that Bath stone appears to stand the weather better in the neighbourhood of the quarries than it does if removed to a distance, or in London; and, judging from the present condition of the oldest houses at Bath in comparison with Bath stone buildings of more modern date erected in London, a casual observer might indulge his imagination with the idea of something being more congenial to the stone in its native atmosphere than if removed to waste and perish in what may be termed a foreign climate. I am ready and willing to admit that there may be a very material difference between the air of Lombard Street or the Royal Exchange, and that of the Land of the Cuckoo and the Nightingale, or any other spot far from the busy world's unceasing sound. But I cannot conceive it probable, that a stone which would last for a century or more in the city of Bath or its environs, would decompose in a quarter of that time were it placed in the Regent's Park. The plain matter of fact is, that the stone used in the construction of the oldest buildings at Bath was procured from the Box quarries, which is in the more important qualities very superior to and far more durable than such as is now generally used. The Box quarry stone is still used occasionally in and about Bath, but the stone merchants in London have long since discovered that the masons will not buy it on account of its being a little coarser and harder, and thereby more expensive to work.

Coombe Down Bath stone was next introduced; it is finer grained, softer, and less durable than the Box stone; but both these have been almost entirely superseded by the grand favourite from Monckton Farleigh, or by what is usually called "Farleigh Down Bath stone." This material possesses all the qualities required by a hasty mason or contractor: it may be sawed dry, like wood, with a common peg-toothed saw, more expeditiously than any other stone; an industrious workman may do almost as much work as he pleases in it, consequently a building may be executed in this stone in a shorter space of time than in any other; and lastly, it decomposes in a shorter space of time than any other stone, hence some people are inclined to think it "makes good for trade."

The restorations of Henry the Seventh's Chapel, at Westminster, were executed in Coombe Down Bath stone, between the years 1808 and 1821, at an expense to the nation of about forty thousand pounds[13]. A large proportion

[13] History, Description, and Account of the Restoration of King Henry the Seventh's Chapel at Westminster. By L. N. Cottingham. 1822 to 1829.

of this amount was for the Bath stone, which has always been about as expensive in London as those of a more durable nature. If an additional ten thousand pounds had been bestowed on labour, in all probability a material might have been selected which would have lasted several centuries longer without being in so decomposing a condition. But whilst the lover of elegant architecture is admiring the extreme attention that has been bestowed in preserving the true spirit of the original design, he will be annoyed at discovering abundant evidences of premature decay. Many projecting parts of that beautiful fabric are conspicuously mouldering away, in less than thirty years since they were restored. A casual observer may, by one glance at the south-eastern towers, convince himself of the truth of these statements; but on more attentive examination, a considerable portion of the masonry throughout the entire structure, especially the more exposed parts, will present multitudes of slight undulations or swellings, somewhat resembling in their progress gatherings or tumours under the skin; these increase in size and number until they meet each other, when they burst, and the surface falls off. This cankering process will be repeated as often as a fresh surface is exposed, until all architectural features are obliterated. Such is the lamentable condition and prospective state of Henry the Seventh's Chapel at this time, that there is every probability of its being in the same dilapidated condition within thirty or forty years that it was in before the repairs were commenced in the year 1808[14].

That there are many stones in the building which at present show no symptoms of decomposition is readily admitted; and those persons who advocate the use of Bath stone for such highly decorative purposes frequently imagine that sufficient care has not been taken to place the stones on their natural bed. The importance of such precaution is generally very considerably overrated; I do not consider it signifies which way a stone is fixed, unless it presents a decidedly laminated structure, which scarcely ever occurs amongst the oolites. A stone of an open, powdery, and slightly cemented texture, will, if exposed

[14] The north front of Westminster Hall was restored with similar material immediately after Henry the Seventh's Chapel was completed; it is now progressing in the same state towards decay. During the spring of the present year (1840), the stonework about the principal entrance was washed by means of an engine; this operation mutilated the projections in a slight degree, the force of the jet of water separated many small portions of stone from the prominent parts that were already in a decomposing state.

The restorations of Westminster Abbey, north side, are proceeding slowly with Bath stone, apparently from Farleigh Down quarries; it is to be regretted that a more durable stone is not used, since there is unequivocal proof of its perishable quality in the adjoining edifice. Since these notes were written, the upper part of the north transept is undergoing repair with a material which appears to be Caen stone.—September, 1840.

to the weather, decompose in a comparatively short space of time, in whatever direction it may be fixed, or whichever surface may be parallel to the horizon.

Another generally received fallacy is the opinion that soft stone will become hard and durable by exposure. Although this notion is true to a certain extent, it is not of sufficient importance to warrant its appreciation in architectural works. All kinds of stone while in the rock, or when recently quarried, are somewhat softer and more easily worked than after they have been exposed to the atmosphere a few months, owing to the stone in its original situation being more thoroughly saturated with moisture than can ever be accomplished after it has been once allowed to get dry. This is a principle well known to masons, for it is a general practice amongst workmen to frequently wet a stone, especially if it be rather of a hard quality, during their operation of working it into mouldings or ornaments, to make it work, as they term it, "more kindly." If the stone be remarkably soft, it is advisable not to let it dry too fast after it has been taken from the quarry, for fear of its cracking, in consequence of the moisture being removed from the outside before the interior of the block can have had time to evaporate; hence, while the central part remains of its original size and extremely damp, the surface will dry, shrink, and thereby cause many invisible cracks, the effect of which will be conspicuous after a sharp frost.

All free-working limestones and oolites become in some degree harder on their surface by exposure to weather. This arises from a very slight decomposition taking place, which will remove most of the softer particles, and leave the hardest and most durable to act as a protection to the remainder. In addition to which, the pores and interstices of the surface get filled with dust and dirt, washed in by rain assisted by powerful winds; all which circumstances help to secure the least protected grains from external violence. If the stone be naturally compact and durable, a surface of this description will materially assist its duration; but, on the other hand, such material as the Heddington stone, near Oxford, or the most perishable Bath stone, will in due time similarly attain a hard crust, which, from the general body of the stone being loose and powdery, is not sufficiently compact to hold on; water will soak in behind the crust, cause a swelling and disruption on the surface, which ultimately breaks. The crust thus opened gradually bends forward more and more, until finally the weight of the disintegrated portion causes it to fall off. In some instances, as in Bath stone, these defective places rarely exceed an inch or two of surface before the decomposed part falls off; whereas the crust of the buildings at Oxford is so remarkably tenacious that it peels off and hangs like rags,

often as much as a foot superficial, before it entirely separates. Upon the whole, I do not consider it a recommendation to a soft stone to say that it gradually becomes harder on the surface.

As Bath stone is decidedly one of the most fragile mineral substances ever used for building, a few observations on its cohesive strength may be offered, less on account of their utility, than because most persons who have investigated the subject of stone for building have expatiated considerably on this head. In all cases which have come within my notice, the stone possessing the least cohesive strength, or that which will crush with less pressure than any other, is nevertheless strong enough, when once fixed, for almost all practical purposes. No architectural members have to sustain greater pressure, in proportion to their size, than mullions of large Gothic windows. The tracery in the great north window of Westminster Hall is now executed in Bath stone, which is remarkable for having the least cohesive strength of all the specimens experimented upon and described in the Report on the Stone for the New Houses of Parliament. Some of the mullions of that window are less than nine inches wide and more than forty feet high, sustaining not only their own weight, but also the whole of the tracery beneath the arch. The eastern window of Carlisle Cathedral, built of a friable red sandstone, is fifty feet high; the mullions are smaller and the tracery much heavier than in that at Westminster; yet in neither of these examples are there any symptoms of crushing. The cohesive strength of stones is never more severely tested than during their conversion by workmen from the rough state to being fixed in their final situation in a building. During these operations, iron levers, jacks, lewises, and various other implements are applied, frequently without judgment, and with but little regard to the mechanical violence which a stone will bear; therefore it may be considered a useful practical rule, that however soft a stone may be, if it resist the liability of damage until out of the mason's hands, there can be little doubt of its possessing sufficient cohesive strength for any kind of architectural work.

At the Isle of Portland there are the remains of several buildings that were erected with stone from the neighbouring quarries, long before that material was generally known or considered of sufficient value to be used in the construction of the principal buildings of the metropolis. A large portion of the island has been the property of the crown during many centuries, and so early as the reign of Henry the Eighth, that monarch caused a castle to be erected at Portland, and another on the opposite shore, near Weymouth; one of these has been

continued as a garrison to the present time, the other has long since been left to ruin; nevertheless the stone with which the walls are built does not appear to have undergone any decomposition worthy of notice. Holinshed, who wrote his Chronicles of England prior to the year 1574, has given rather a long account of Portland Isle; he has also, in another part of his works, devoted an entire chapter to the subject of "Quarries of Stone for Building;" but in neither case has he made even the slightest allusion to Portland stone. Camden the historian (who died in 1623) has also minutely described the Island of Portland, without mentioning the stone quarries; and it is worthy of remark, that in the next paragraph he describes the Island of Purbeck, distant about fifteen or twenty miles, as having "many sorts of good stone, from which large quantities are carried to London, to the great advantage of the inhabitants." From these two eminent writers being wholly silent on the subject of Portland stone, we may reasonably infer that at that time it was a material not generally known or used, except in the immediate vicinity of the quarries.

James the First appointed Inigo Jones his chief architect and surveyor general of his majesty's works; under this appointment he had to survey the crown lands at Portland; and his discrimination very soon led to the introduction of Portland stone for all the principal buildings in and about London. The banquetting room or military chapel at Whitehall was begun in the year 1619, and finished in two years. As far as I can search or learn, this is the earliest building of magnitude constructed with Portland stone in London, or at any considerable distance from the quarries. In 1631, Inigo Jones received orders to repair the old cathedral of St. Paul's; this was performed by "casing great part of the outside, and adding a grand Corinthian Portico to the west front, all of Portland stone." From that time it became the chief material used for ornamental architecture, not only in the south of England, but in many parts round the coasts of this country and Ireland.

After the fire of London in 1666, up to the beginning of the present century, the architects and builders of London scarcely ever thought of using any other kind of stone, except for pavements and similar subordinate purposes. Sir Christopher Wren used Portland stone for St. Paul's Cathedral and other public buildings, because he considered it the best material then known, and on account of the quarries belonging to the crown, as well as their being most eligibly situated for water carriage. Among the writings of Sir Christopher Wren relative to the stone for St. Paul's, he states, that "All the most eminent masons of England were of opinion that stone of the largest scantlings were there to be found, or no where. An inquiry was made after all the good stone

that England afforded; and next to Portland, Rock Abbey stone[15], and some others in Yorkshire, seemed the best and most durable; but large stone for the Paul's works was not easily to be had even there[16]."

At first, all the stone brought from Portland was obtained from the crown lands on the north-east of the island; but as the demand increased, private property in different parts became more valuable, and large quantities of stone were brought from the west and south-east cliffs, without the slightest regard to quality, durability, or any other consideration of fitness, except that of meeting with an immediate sale in the market. I have carefully looked over many specifications for public and private buildings, and find the materials usually described to be of the best quality; but the general tenour of those parts describing the stone to be used rarely amounts to any thing more than the mere well known name, preceded by an adjective, such as "*good* Portland stone," but what is to constitute that "*goodness*" is altogether undefined.

Large quantities of Portland stone of an inferior quality are brought to London, not because the island is deficient in the best kind, but because all our large buildings are executed by contracts, at so remarkably low a price, that the mason's study is not what kind of stone will be most durable, but what stone can be wrought by the workmen most expeditiously, and thereby yield the largest profit; and of course the proprietor of the quarries will only send such stone into the market as is likely to suit his customers. St. Paul's Cathedral, and many of the churches and other large buildings, erected in the reign of Queen Anne, were constructed with stone very superior, as far as regards durability, to the greater quantity now used; and yet the quarries from whence those sources were derived have been deserted beyond the memory of any inhabitants now living at Portland; and the only reason assigned is, because the merchants find they cannot sell such stone, on account of its being a little harder, and thereby more expensive to work.

Whenever a number of large buildings are being erected at the same time, the demand for stone of the best quality is greater than the quarries already opened can supply. The contractors are bound under a heavy penalty to finish the work by a given time, and hence are compelled to use a material which perhaps they would otherwise reject. It may be owing to circumstances of this kind that portions of the stone used in buildings so recently erected, as the Park entrances from Piccadilly, are already in a state of decomposition; the same

[15] The ashlar at the east end of Greenwich Hospital appears to be Roche Abbey stone, which is likely to be the case, as Sir C. Wren had a high opinion of that material.

[16] Parentalia, page 288.

remarks may be applied to some of the stone used about the new buildings of the British Museum. Most of you are probably aware of the deplorable condition that Blackfriars Bridge was in before the repairs were commenced: I have been informed by persons who recollected the building of it, that the masonry presented innumerable evidences of slow, though certain decay, before the bridge was quite finished, in the year 1770. I shall notice one more example, merely to show how completely this subject has been neglected heretofore, even by men of first-rate eminence. He, whom we all admired for his abilities and munificence, who had risen to the most distinguished rank in his profession, whose perception and discernment in most things were more acute than in the generality of men; yet the late Sir John Soane, about twenty or twenty-five years since, allowed the front of his own freehold residence in Lincoln's Inn Fields to be constructed with Portland stone of such an inferior quality, that it is already evidently mouldering away. It is probable that too much confidence was placed in the mason, who ought to have known better, and have acted differently.

Abundant examples of defective Portland stone might be pointed out; but when we consider that the stone brought from the island, good, bad, and indifferent, is all shipped from the same pier, which is a very small one, and that notwithstanding the blocks are marked in the quarry, so as to denote from whence they were obtained, it is possible that some of them may be misplaced; hence we ought not to be surprised if occasionally a very bad stone is conspicuously placed in a building that is otherwise in excellent condition; and this we find more particularly to be the case in our modern structures, arising no doubt sometimes from ignorance or inattention, but often from some trifling interest, such as using a stone because it is just of the dimensions required.

These events seem to have brought about an important investigation, in which the reputation and interests of persons connected with architecture are deeply concerned. The Portland merchants had enjoyed the supply of stone to London and the south of England for an almost uninterrupted period of more than two hundred years: I say almost, because in the year 1804 a duty of 26*l.* 8*s.* per cent. was imposed on all stone conveyed by sea from one port of Great Britain to another. This was a temporary injury to the Portland trade, for large quantities of Bath stone were brought to London by canals, and consequently free of duty; but in 1823 the coast duty was taken off, and Portland again took the lead for all superior buildings. But its character was stained, and public confidence was lost, in consequence of a few individuals bringing shiploads of rubbishing stone into the markets, which was used by the unwary masons for

all purposes. Many of our noblest structures which were constructed with these defective materials rapidly assumed the appearance of premature ruin; the architects and proprietors of buildings united in one universal outcry against all kinds of Portland stone; and it has been condemned, without inquiring into the cause of complaint, as wholly unfit and unworthy of being used in substantial edifices.

To explain and illustrate the numerous qualities and localities of Portland stone, would far exceed the usual limits of an essay. You will see by analyses[12], that the ingredients are apportioned in this stone much the same as in most other oolites; therefore its quality depends greatly upon the manner in which the component parts are united. There are not fewer than fifty or sixty quarries already opened at the Isle of Portland, most of them along the north-east and north-west cliffs, at an elevation of several hundred feet above the sea. The stone from each of these quarries, and from different beds in the same quarry, almost always presents some minute particularities, which, on very attentive examination, will serve to distinguish it from others. In many instances these distinctions are so conspicuous as to be evident on the most casual inspection.

By minutely and attentively examining a specimen of Portland stone that is found, after fifteen or twenty years' exposure to the weather, to be in a decomposing condition, its characteristic features will be, on the whole, lighter coloured than such as is known to be good stone; arising partly from the entire mass being less crystalline, and from spots, veins, and rings of a lighter tint than the ground. The whitest parts are generally least cemented and most friable; the stone is altogether of an open, powdery texture; and the pores or vacuities being numerous compared with the bulk of solid matter, render it deficient in weight for its size.

Portland stone of the most durable quality is comparatively heavy, of a uniform colour, rather darker than the last described, owing to the quantity of cement, of a compact crystalline texture, regularly dispersed throughout the pores; and hence it will resist a greater force to crush it, or to disintegrate the particles. The following comparison will show the relative peculiarities of good and bad Portland stone; considering the specimens, when examined, subject in every respect to the same conditions, such as being equally wet or dry, &c.

GOOD.	BAD.
Preponderance of weight	Deficiency of weight.
Dark coloured	Light coloured.
Uniform colour	Party coloured.
Compact and crystalline	Open and powdery.
Hard to crush	Friable.

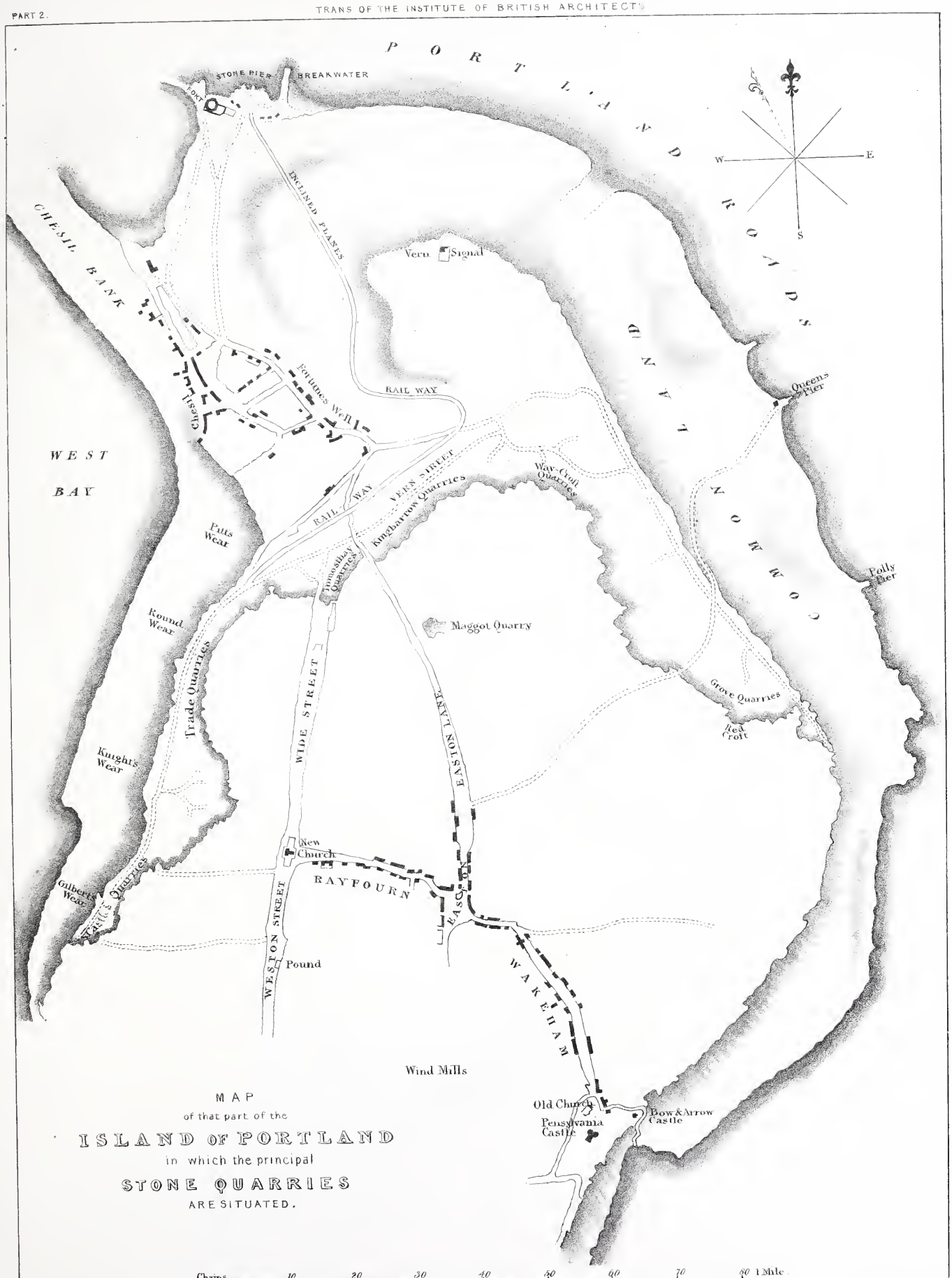
What are technically called "glass veins" vary from a line to an inch or more in breadth, and often run completely through a block: they retain their original whiteness, while all the remaining surface becomes covered with lichens, or, if in London, with soot and dirt; whereas the "party-coloured" just named looks more as if some whitish fluid had been sprinkled or thrown upon the stone in patches. Glass veins may be considered unsightly, but they are by no means perishable, neither do they facilitate decay in any way whatever. If they occur in steps, pavements, or any other situation subject to considerable wear, their hardness will soon occasion them to be conspicuously above the general level; therefore such variation of colour is no defect beyond appearance, and causing a surface to wear irregularly.

According to the observations of Professors Daniell and Wheatstone, at the end of the Report on the Selection of Stone for Building the New Houses of Parliament, the following inference may be drawn: that in all stones of the same class, the heaviest kind, or that which has the greatest specific gravity, is the most durable and best suited for architectural works; this is given as a sort of general rule, "though liable to individual exceptions;" but it appears to hold good with all the varieties of Portland stone. The specimens from which the following weights have been obtained are among those which have been most tested by exposure to weather.

	Weight per Cubic Foot. lbs.	oz.	drs.
Grove quarries, best or lower bed, stands the weather pretty well [17]	147	10	11
Way-croft quarries, top bed, best stone in the island	135	8	12
Vearn-street quarry, top bed	134	10	0
Castles quarry, between the flint beds, decomposing quality	132	5	8
Gosling's quarry, bottom bed, decomposes rapidly	131	4	8

If a line be drawn across the northern part of the island, taking a direction from north-east to south-west, the best stone for standing the weather will be found in the quarries at the north-eastern extremity of such line; and as you quit this district, and approach the south-western quarries, so in proportion is the stone less and less durable. The most ancient buildings in the neighbourhood, namely, a Tudor house in the village of Wakeham, ruins of Portland old Church, Bow and Arrow Castle, and Sandysfoot Castle, are generally in excellent condition; they are constructed with stone precisely similar to that of

[17] The reason of this stone being so much heavier than any other marketable stone in the island, is its being so full of shells, which are of much greater specific gravity than the general mass; we must not thereby infer that this stone is considerably more durable than any of the others, notwithstanding its weight far exceeds them.



MAP
of that part of the
ISLAND of PORTLAND
in which the principal
STONE QUARRIES
ARE SITUATED.

C.H Smith del

Day & Haghe Lith^rs to the Queen.

the north-eastern part of the island, where very old quarries, long since deserted, may still be discovered.

In giving a general description of Portland stone, it may be necessary to observe, that the entire island contains the same general strata throughout, measuring a collective thickness, between the dirt bed upwards and the kimmeridge clay beneath, of from twenty to thirty feet of actual block stone. I shall endeavour to describe the various strata, chiefly as they occur in the north-eastern district, or that part of the island from whence the best stone is procured; and afterwards notice the principal differences which characterize the several beds of stone in some other quarries in the island.

About four feet below the grass commences the first stratum of thin rubble, from half an inch to four inches in thickness, and occupying a depth of from four to ten feet; the best is occasionally used for rough pavements, and as a substitute for slates or tiles for roofing the humbler buildings in the island. Beneath this is the celebrated "dirt bed," containing the fossil roots, stumps, and branches of trees, mostly in the precise situation where they grew, fructified, and perished[18]. The top cap is a light-coloured, fine-grained, dense limestone; shattered, full of cracks, easily separated into many small lumps, and too hard for useful purposes. The skull-cap is irregularly compact and open; large blocks, occasionally containing flints and cherty nodules, may be obtained tolerably sound, rather hard, the grains well cemented together; and there is good reason to believe it to be a durable stone, well suited for bold massive structures, where little or no ornament is required. The roach, both of the top and bottom beds, is always imperceptibly incorporated with the free-stone which is invariably situated beneath it. The roach is peculiar on account of its composition, being in every respect the same as the stone with which it is gradually united, but replete with cavities left by shells, some entirely, others partially decomposed. Although this stone is so completely full of holes as to present the idea of its having been eaten or partially decomposed by insects, nevertheless, in the roach of the top bed, the grains which compose the solid portion are united with so firm and excellent a cement of carbonate of lime as to render the whole extremely durable. Such as is nearest to the free-stone is generally finer, that is, the holes are smaller; this kind has been used at Portland in the construction of the new church, built in 1766, and in part at Sandysfoot Castle, near Weymouth, built in the time of Henry the Eighth: in both cases the original tool marks are still apparent. It has been used in later times

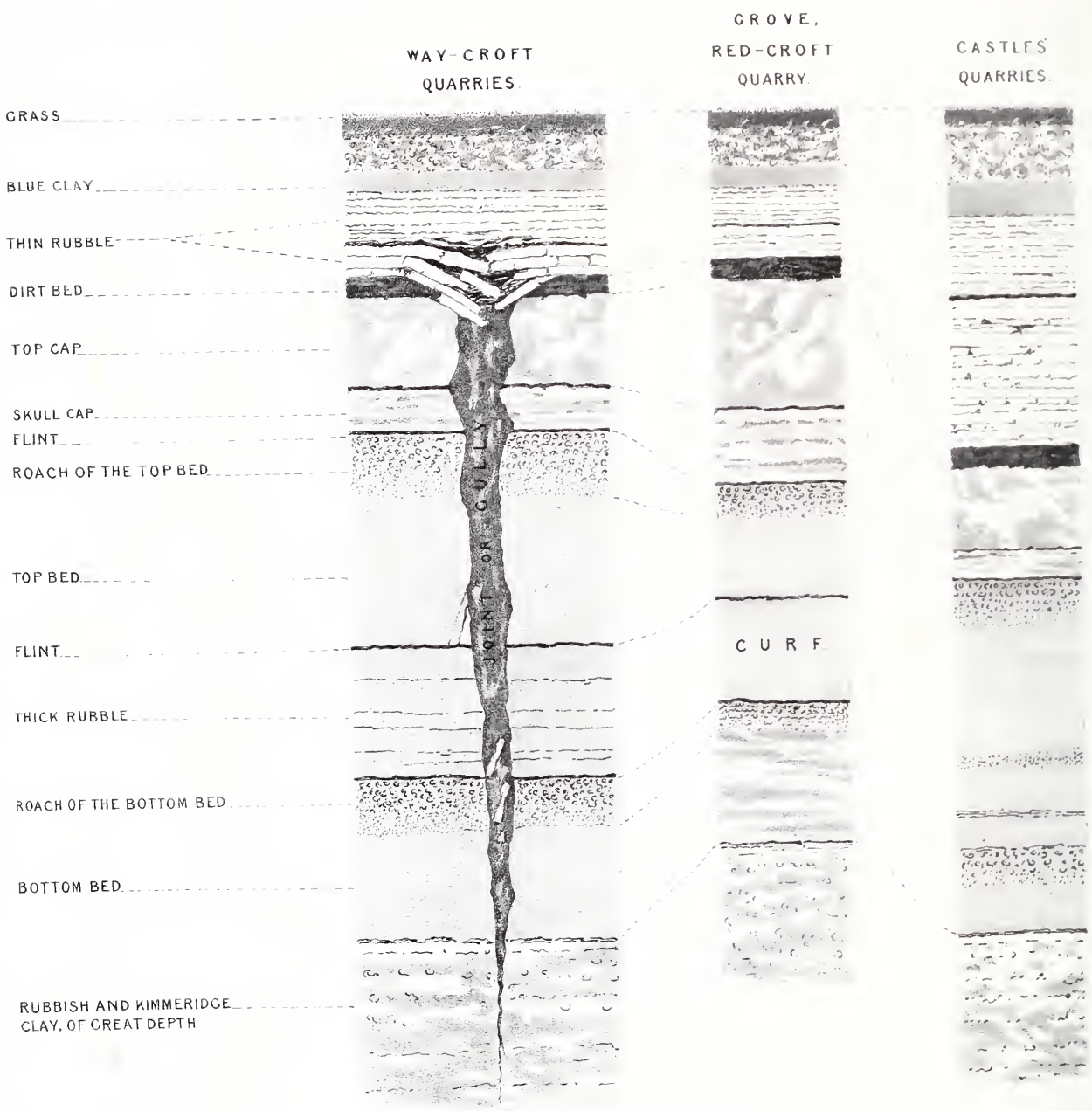
[18] An interesting account of this remarkable stratum may be found in nearly all the principal geological works.

in very trying situations, such as the waterfall from the Serpentine River in Hyde Park, also in that part of the new bridge over the Thames at Kingston from the foundation to several feet above water, and it appears to resist these severe tests amazingly well.

The most perfect quality of Portland stone, known to the merchants and quarrymen by the name of top bed, is situated about midway between the top and bottom of the quarry, immediately beneath and attached to the roach just described. This bed varies in thickness from five to about seven feet, although occasionally blocks are obtained upright in the north-western quarries measuring ten or eleven feet, but the lower end of such blocks will very seldom stand the weather. A small portion of roach is generally left on the end of long blocks, which may be unsightly; but it indicates to a certainty which way the stone lay in the quarry, the roach invariably being uppermost, and the nearer to the roach the better or more durable the stone; consequently, in very exposed situations, it is advisable rather to leave a few holes of the roach in the finished mason's work, than to subject the lower part of the block, which is always finer grained, and apparently better stone, to all changes of temperature and severities of the weather; because the end farthest from the roach has always a tendency to decompose first, especially if the block be unusually long.

A layer of chert or imperfectly formed flint, about four inches thick, frequently containing numerous shells and cavities from animal remains, is always found adjoining the lower part of the top bed; under which six or seven feet of thick rubble, or coarsely-formed stone, in several beds, rests upon the roach of the bottom bed. To all appearance this roach is the same as that upon the top bed, but it differs essentially in being much less durable, and is, on that account, totally unfit for external uses. The bottom bed, or, as it is sometimes erroneously called, "best bed[19]," is the lowest stratum in the quarry, and averages about six feet thick. The component parts are the same as those of the top bed, but not so well cemented together, being always more or less in a loose and powdery state, consequently, if exposed to the weather, it very soon decomposes. Some of the bottom-bed Portland is so soft to work, beautifully fine-grained, and homogeneous, that it may be considered equal to the Maltese,

[19] Formerly, when none but east cliff quarries were worked, the lowest bed was considered the best stone: hence the name amongst the quarrymen of "best bed;" but in the north, north-east, and west cliff quarries, the top bed, though not always the finest grained, is certainly the best stone for standing the weather. Nevertheless, amongst the stone-merchants and people of Portland, the lowest stratum all over the island is to this day frequently called "best bed," which is very likely to mislead those persons who are not aware of the technical distinctions, and thereby unintentionally cause defective stone to be used in situations where it will be sure to decompose prematurely.



PORTLAND QUARRIES.

SECTIONS OF STRATA IN DIFFERENT PARTS OF THE ISLAND.

G.H.SMITH.DEL.

DAY & HAGHE LITHRS TO THE QUEEN

Painswick, Totternhoe, or any of the superior free stones that are now so often used for Gothic monuments, altar or organ screens, florid shrine-work, or any other small and delicate carving for interior decorations securely protected from the weather.

The annexed plate represents three sections of strata in different parts of Portland Island, as far distant from each other as the quarries already opened will admit (see the Map). The stratification varies in thickness from north to south. This is conspicuous in the Way-croft quarries, where the top bed is double the thickness of the corresponding bed in the Grove quarries; the former is perhaps the best stone in the island, whereas the latter is so coarse and inferior that it is rarely or never used. Between the top and bottom beds in the Way-croft is a quantity of thick rubble in several strata, collectively answering to a single bed, called "curf," which occurs in a compact state, about five feet thick, only in the Grove or southernmost of the quarries on the east cliff. At the Castles, and other quarries on the west cliff, the beds are not so distinctly separable, and roach is occasionally incorporated with the free stone in beds, where there is none to correspond with it, in the stone of the north and east cliffs.

The joints or fissures are what the quarrymen call "gullies;" they are always tolerably vertical, and extend considerably in various directions with little or no interruptions; they are very narrow in the lowest bed, and widening upwards, through all the solid rocks, to about two or three feet wide at the highest part. They never reach above the top cap, although the effect of separation is conspicuous above the dirt bed, where the thin rubble generally appears disturbed precisely over the gully, as if by some kind of subterranean movement, without the effect being felt by any of the superincumbent strata. The distance of these gullies from each other varies from about three to fifteen feet.

By thoroughly investigating the physical qualities, and rationally observing the various peculiarities in the several beds of Portland stone, it will be evident that they all possess characters essentially different. Some are applicable to many uses, but each has at least one particular adaptation to which it is most suited; and it is the interest of architects, stone merchants, and quarrymen, to seek every opportunity for obtaining correct information as to their fitness. A block of stone may be applied to a particular purpose, and placed in a situation for which it is quite unsuitable, thereby considerably assisting its decomposition; in which case a good material has probably been misapplied, and then unjustly pronounced to be defective. We might as well expect the wood of every kind of fir tree to be equally durable, in whatever situation it may be placed;

but experience teaches that the white varieties of pine or deal are admirably adapted for furniture, mouldings, and the generality of interior joiner's work, and that they will decay rapidly if exposed in a damp situation; whereas yellow deal and Memel timber, which are also fir trees, will last infinitely longer subject to the same variations of weather.

Merely for want of a right understanding, the present system of the Portland trade is prejudicial to the interest of all parties concerned in it. To get at the top bed, which is the only marketable stone of a really good quality, the entire bed of scull-cap is obliged to be removed; and, notwithstanding it is said to be durable, besides being well adapted for bold massive structures in exposed situations, it has never been applied to any such useful purpose. The reason assigned is, its quality being rather hard, and sometimes coarse. The merchants never, under any conditions whatever, find a purchaser for this somewhat valuable material; therefore, to get it out of the way, it is either buried in an old quarry, or thrown off the cliffs towards the sea, at a considerable expense for labour[20], which must, of course, be charged upon the stone that is of a saleable quality. There is also an objectionable system of traffic carried on to a vast extent in London, arising sometimes from pure ignorance, but I fear frequently from sordid motives; namely, that of selling and using bottom bed stone as a material for external use, or for pavements and steps, for which purpose its softness will occasion it rapidly to wear away[21]. Whoever is well acquainted with the quarries, and with the different kinds of Portland stone, must admit that a great temptation is offered to stone-merchants to supply the markets with bottom bed stone, without designating it as such[22]. A very large proportion of the expense of procuring the good stone is caused by the necessity of removing the superincumbent rubbish; but when this is accomplished, and the really good stone sent to market, a comparatively small expense of labour will enable the quarrymen to get at the lowest stratum; which is a

[20] Although from seven to ten feet in thickness of solid stone is taken out of the quarries, the quantity of rubbish, including the waste stone from squaring the blocks, is so great, that it cannot be stowed close enough, after having been once disturbed, to get it into the same space which was previously occupied by a more densely compacted mass; therefore immense quantities are thrown down upon the undercliffs or "wears," for which accommodation the lord of the manor receives from the proprietors of the quarries a certain sum of money per ton, or per annum, according to agreement.

[21] At St. Katharine Dock House, the steps of the great staircase, and the pavement of the passage leading from the principal entrance to the long room, were made of such soft Portland stone, that in many places they were worn down three or four inches, and obliged to be repaired, within ten years after the completion of the building.

[22] Some of the Portland merchants never allow bottom bed stone to be sent from the quarries without the blocks being marked thus—"Curf," or "B. Bed," as the case may be.

material sure to meet with a ready sale in the market, because it is generally the most beautiful looking stone, much softer, and consequently much less expensive to work, than stone of a more durable quality. Hence masons and contractors are tempted to use it for all purposes, regardless of situation or exposure to the inclemency of all seasons.

It is desirable that some plan should be adopted, in order to secure a certain cooperation and right understanding between all persons concerned in the use of stone as applied to buildings, so that the public may not be disappointed by the premature decay of an edifice which had been erected under the impression of its lasting for ages. If a merchant or vender of articles of daily consumption supply his customers with inferior goods, when only those of the best quality are ordered, such a practice is soon detected, and he is punished either by having them returned, or by the loss of his customers, when they discover that his goods are not of the quality intended; but when defective stone is used in a building, the failure is perhaps not very evident during the lifetime of the parties concerned in its erection, and cannot therefore be detected till too late for redress.

It has been deemed expedient, for the protection of the public, to legislate between the buyer and seller of certain articles, the quality of which may be determined at once by persons of the meanest capacity. The coal-merchant, for instance, is compelled to sell by certain regulations laid down by act of parliament; and why should not the mason or stone-merchant be under the same obligation to deliver only such articles as they engage to supply; the quality of their goods being much more difficult to ascertain?

A specification of masons' work should contain, not merely the popular name of the stone, but also the correct name of the quarry, and of the particular stratum or bed, if there be an evident difference, in such quarry; a sample of which should be selected by the architect, and retained in his possession, but open to the inspection of contractors previously to making their estimates, with an understanding that the whole of the stone used is to be of a quality not inferior to the sample. For the satisfaction of the contractor as well as the architect, when the contract is being settled, the sample of stone might also be signed and sealed, to remain for comparison with the stone used in the building till the work be completed.

If the natural texture or disposition of the particles of two or three stones could be conveniently examined upon an extremely magnified scale, no person would imagine that to be the most durable which had scarcely any cement to unite the grains together. It requires no great stretch of philosophical inves-

tigation to understand, that whatever the cement may be, that stone which contains the largest quantity of cement in the interstices between the grains will certainly be least affected by external influences. In a stone that is very open and porous, each component grain on the outside has very nearly all its surfaces exposed to the action of mechanical violence, such as the freezing of water, after being forced into or absorbed by the external portions of the stone. The solvent power of water, even in its simplest state, is a fact so notorious, that the mere allusion to it seems almost needless. And the atmosphere, especially in England, is always charged with a sufficient quantity of aqueous vapours to engender inevitable decomposition in a stone of a slightly cemented and powdery nature. The chemical action of a humid atmosphere, in conjunction with powerful winds and driving rains, produces a decomposition of the entire surface of limestones, commencing with the particles which have the weakest attachment; whereas the same action, if all other things be equal, will only affect the cementing substance of sandstone, the grains of quartz in it being comparatively indestructible. But in either of these cases, whether chemical or mechanical, the stone that is closest in texture and most crystalline will also be the least porous, consequently it will present the largest portion of matter in a given space to resist decomposition. But, like the fable of the "bundle of sticks," the more the grains are separated from each other, the more readily will the whole be destroyed. A stone may be very porous, consequently very absorbent, and yet sufficiently durable for architectural purposes. Its durability depends upon the cement being strong enough to resist the mechanical forces to which I have alluded. By this statement I do not mean to infer that absorption is a desirable quality; a stone may be comparatively like a sponge, and yet last for ages without any material decomposition; but if two kinds of stone were equal in every other respect, that which will soak up least water will certainly be the most durable. Few mineral substances will hold more water than a good graystock brick, which will probably last as long as any stone, because its component parts are held together by a strong vitreous cement; but a clinker brick is less absorbent, because it contains a greater quantity of the same kind of cement, and is therefore less likely to yield to the same atmospheric influences.

In almost every limestone quarry or locality, but more particularly amongst the oolites, there are different qualities of stone, some tolerably good, others very bad. The principal requisite is judgment, to select that which is best. I have already pointed out the necessity of this qualification for the Portland quarries, and extraordinary instances of the want of it may be found in buildings

of stone from the Doulting quarries. For example, many parts of Wells Cathedral and the adjacent buildings are in a very decomposed state; whereas Glastonbury Abbey, built of similar stone, and no doubt from some of these quarries, is in an extremely perfect condition, although two or three hundred years older than the buildings at Wells.

There are several physical laws by which the decay of stone is effected, though not much noticed or easily explained. Sir Humphry Davy[23] considered the silent and slow operation of electricity, as a chemical agent, not only as directly producing an infinite variety of natural changes on the surface of stones, but as influencing nearly all which take place. Probably no two substances, or distinct parts of the same surface, are to be met with, but are in different electrical relations to each other, and incessantly exerting their power of attraction and repulsion. Such gradual and generally unobserved influence on the decomposition of matter is more worthy of notice in the economy of nature than the grand and impressive phenomena of lightning and thunder. The vicissitudes of heat and cold, dryness and moisture, frequently alternating, during a long period, are infinitely more destructive to stone than either of these extremes constantly operating. It is well known that variation of temperature causes all bodies more or less to expand or contract; if the mass is made up of different substances, some will increase more in proportion to their size than others, which must tend to loosen the component parts, and thereby separate many small fragments from the surface of stones. The sun never shines upon the north or north-east sides of a building, except very obliquely at rising and setting; but the south and west fronts have the same degree of cold as the north and east during the night, with the additional temperature of meridian splendour daily. This mode of reasoning is borne out by the test of time, for in all cases the greatest amount of disintegration has taken place where the inequalities of temperature are greatest. The north and east sides of old buildings are almost universally in much better condition than the south and west sides, provided the latter are freely exposed to the solar rays, and the more frequent winds and rains from those quarters.

I do not quite agree with the opinion, which upholds frost as an agent so important in the decomposition of stone as it is usually ascribed to be. There are many instances which cannot be satisfactorily traced to such a source; however, some most ingenious theories have been devised, for the purpose of what is termed "imitating the action of the atmosphere during successive winters on

[23] Consolations in Travel, or the Last Days of a Philosopher. Dialogue the Sixth.

the surface of stones," and by such means to form a standard of experiments of universal application. The plan of Monsieur Brard, as fully described in the thirty-eighth volume of the "Annales de Chimie et de Physique," where is also to be found an account of experiments made by members of the public commission appointed to ascertain its efficacy, seems to have been received by critical assent, both in France and England, as fully answering the intended object. I am aware of the boldness of venturing an opinion opposed to that which has received such general approval; but the humblest sentiments, originating from practical observations, may evince some trace of those principles which regulate and recommend the more scientific productions. We are told that the plan recommended by M. Brard may be considered very closely to represent the action of the atmosphere during successive winters on the various stones submitted to examination; but I candidly confess it is not in my power to explain or to comprehend the resemblance. The plan is simply this. Provide a saturated solution of Glauber's salt in cold water, boil it, and, while boiling, put the specimens in without removing the vessel from the fire; after half an hour's boiling, the stones are to be taken out and suspended by a string over a vessel containing some of the solution; as often as they dry and present an efflorescence on their surfaces, plunge them again into the solution; after this has been continued during five or six days, the specimens and the disintegrated particles in the vessel are ready for examination.

If we compare this mode of treatment with that of nature and the usual effects of atmosphere, it will be found to vary materially both in detail and result. In the first place, Glauber's salt, which is a neutral mixture of sulphuric acid and soda, will produce a slight chemical decomposition off the surface of limestone; this will be evident by experimenting, as described above, on a piece of polished Carara marble, after which scarcely any trace of the original polish will be perceived, an effect not to be produced by water in its simplest state. Much stress is laid upon the remark, that great care must be taken not to saturate the water whilst it is warm, for fear of making the solution too strong of the salt; whereas boiling the mixture being a kind of distillation, the water will be driven off in steam, leaving the solution more and more strong. But the most remarkable deviation from nature in this plan is, in expansion. The very simple experiment of filling a bottle with a saturated solution of Glauber's salt in boiling water, and corking it tight while hot, will show that in this state it will not crystallize even when perfectly cold; but if the cork be removed, crystallization will instantly take place, and in a minute or two nearly the whole contents will be changed to a mass of crystals without the slightest injury to

the bottle;[24] a proof that if any expansion had taken place, it is not appreciable; whereas had the bottle been filled with water, and then frozen, it would certainly have been broken, by that very remarkable property of water, its expansion by cooling, and increasing in bulk while changing from the fluid to the solid state. This surely is a difference in the two processes deserving the utmost consideration. Again, what can be more at variance with the action of weather than plunging the stones instantly, from the temperature of an ordinary atmosphere, into a boiling mixture, and keeping them in it half an hour, thereby producing, by suddenly raising the temperature on the surface, considerable dilatation and separation of the external particles, before the interior can have been influenced by the sudden transition?

It may be imagined that, notwithstanding these apparent discrepancies, the effect produced answers the intended object, and may be depended upon, as at least an approximation to the effect of weather on the same substances during a long period. We are apt to pass over the real position of an object while searching diligently where we wish to find it; in like manner, it sometimes happens that philosophers overlook simple matters of fact, while they pursue with enthusiasm whatever is likely to confirm and establish some favourite hypothesis. Respecting the practical value or confidence to be reposed in M. Brard's plan of trying stones, we have fortunately something more satisfactory to proceed upon than mere circumstantial or presumptive evidence. Time has secured for us the most essential and veracious witnesses: if his mode of treatment be applied to stones similar to such as are known to have been used in the construction of old buildings, we shall draw no inference favourable to the method proposed.

The following progressively arranged table, selected from the Parliamentary Report, will show the weight of particles disintegrated, in grains and decimals, from two-inch cubes of the several stones named, after having been subjected to Brard's process for eight successive days:—

	Grains.		Grains.
White Steetley	0·4	Binnie	1·4
Craigleith, liver rock	0·6	Bolsover	1·5
Roche Abbey	0·6	Park Nook	1·8
Bramham Moor	0·7	Huddlestone	1·9
Giffneuk	0·9	Brodsworth	2·2
Morley Moor	0·9	Portland, Way-croft	2·7

[24] This experiment will sometimes fail, in consequence of an unfavourable state of the atmosphere at the time the cork is removed; but if a crystal of Glauber's salt, no matter how small, be dropped into the fluid, the whole will instantly shoot into crystals.

	Grains.		Grains.
Mansfield, White	3·0	Taynton	8·5
Jackdaw Craig	3·1	Ham Hill	9·5
Ketton	3·3	Chilmark	9·8
Park Spring	5·0	Bath, Box	10·0
Cadeby	6·4	Heddon	10·1
Ancaster	7·1	Haydor	10·9
Mansfield, red	7·1	Barnack	16·6
Kenton	7·9	Totternhoe	22·3

According to the tenour of M. Brard's description, such stones as will bear the effect of weather best should be sought for amongst those at the beginning of the list; and those of the most decomposable quality near the end of it; but there appears nothing tending towards uniform progression of that kind. I shall only allude to such specimens as are well known to have been long tested by exposure to weather and very differently affected by Brard's method; which, if it imitates nature, should produce something like the same relative effect on the various stones experimented upon. There are so many instances of Roche Abbey mouldering away, even after a few years' exposure, that its name ought not to appear amongst stones of a good quality; many sepulchral monuments have recently been erected with Roche Abbey stone in Hackney churchyard, all of which exhibit evident proofs of decomposition. The lower part of King's College Chapel, at Cambridge, is built with Huddlestone, and is now in a very mouldering condition. Doncaster old church, built with Brodsworth stone, is now undergoing a very extensive repair, in consequence of the stone being so much decomposed. Stone from Jackdaw Craig has always been used for the construction and repairs of York Minster, the whole of which is in a sad state of decay proportionate to its age. Approaching the other end of the list, we find Taynton, Ham Hill, Chilmark, and Barnack amongst those which disintegrate the most by Brard's process; whereas Taynton stone is remarkable for its very perfect condition, wherever it has been used at Oxford. The same may be said of Ham Hill, a stone extensively used in the neighbourhood of the quarries. Salisbury Cathedral, built with Chilmark stone, is generally in an excellent state of preservation. But the greatest deviation from the expected result, by the method proposed, is Barnack being so very low in the list; in fact it disintegrates more than any of the others, except Totternhoe; and yet all the old buildings at Stamford, and for many miles round the quarries, including Peterborough Cathedral, which are built with Barnack rag, are generally in a wonderfully good state of preservation.

Having taken these circumstances into consideration, and compared them

with the evidence afforded by old buildings, we must conclude, that it requires the utmost caution before we attach importance to any kind of hypothetical reasoning which is not directly or indirectly supported by established physical truths. However ingenious the plan recommended by M. Brard may be, the effect produced on the stones by his experiments is, in the greater number of instances, diametrically opposite to that which would result from the action of weather on similar materials after having been exposed to its influence many years; consequently such a mode of procedure is not to be depended upon, and will always be liable to lead to erroneous conclusions.

Having pointed out the objections to M. Brard's method of testing the durability of stones, and shown that his contrivances are unsatisfactory, it is nevertheless out of my power to recommend a process which shall be found infallible under all circumstances. If we consider the various conditions of the mechanical, chemical, and mineralogical arrangement of the particles which compose the numerous kinds of building stones, there is quite sufficient reason to doubt whether any general principles can be established. Probably no cause of failure, in stones resisting the decomposing influence of weather, is so common as that arising from their containing a quantity of uncrystallized dusty matter, in the interstices between the more solid particles; which may be detected by examining a new fracture with a powerful magnifying glass, and disturbing the powder with the point of a needle. Or a more effectual method is, to break off a few chippings, about the size of a shilling, with a chisel and a smart blow from a hammer; put them into a glass about one-third full of clean water; let them remain undisturbed at least half an hour; the water and specimens together should then be agitated by giving the glass a circular motion in the hand. If the stone be highly crystalline and the particles well cemented together, the water will remain unaltered, clear, and transparent; but if the specimen contains uncrystallized earthy powder, the water will present a turbid or milky appearance in proportion to the quantity of loose matter contained in the stone. The stone should be very damp, almost wet, when the fragments are chipped off, otherwise the blow of the hammer will shake out much of the dust before the pieces are put into the water. I have applied this mode of treatment to numerous stones, including many whose qualities have been proved to be good, bad, or indifferent, by long exposure in old buildings, and have generally found it to be pretty correct.

The value or usefulness of an experiment is sometimes increased in proportion to the facility with which it may be performed by inexperienced persons, and under very disadvantageous circumstances. A process such as I have

just described may be applied any where, with no other apparatus than may be found even in every cottage or road-side public house, and for this reason it is presumed that it may occasionally be useful, although it should be clearly understood that I do not offer it as an infallible test. There are instances among the oolites, though of rare occurrence, of stones containing a superabundance of crystalline calcareous cement, irregularly dispersed, so as to give the stone a variegated appearance. Taynton is of this description; the ova, being extremely soft and distributed in patches, will, in certain parts, wash out from the surface by the process just described, and thereby produce the milky appearance in the water, notwithstanding that such stone is extremely durable, because it contains so large a quantity of excellent cement.

Trifling and unimportant as most of the circumstances which I have named in the progress of this inquiry may seem to be, it must be recollected that the individual grains which compose the most stupendous rocks are also in themselves trifling; and all the effects of decomposition to which I have alluded may be imperceptible in days or even in years, but a limited and insignificant cause will produce a very surprising effect if continued for ages. Throughout the whole of this essay, the drift of argument has been chiefly directed towards the causes of failure; consequently, by endeavouring to trace them to their source, we shall be able to avert the evil in future: or, as Sir Humphry Davy has beautifully remarked, "If human science has discovered the principle of the decay of things, it is possible that human art may supply means of conservation, and bestow immortality on some of the works which appear destined by their perfection for future ages."

ON WARMING AND VENTILATING THE LONG ROOM OF THE CUSTOM HOUSE, LONDON, UPON DR. ARNOTT'S PRINCIPLE.

By CHARLES FOWLER, Hon. Secretary.

Read at the Ordinary Meeting, July 13th, 1840.

IN the present advanced state of Science and Art, and the consequent increase of comfort and refinement in every rank of society, the subject of warming and ventilating buildings has become of paramount importance, and forms an essential consideration for the Architect in determining their arrangement and construction.

In reviewing the experience of many years past, numerous important results present themselves. Large sums of money have been expended, and great sacrifices made, in altering and adapting buildings for the introduction of the various modes of warming, by steam, hot water, or heated air, with their costly and cumbersome apparatus of furnaces, boilers, pipes, flues, &c. Most of these have been found more or less liable to objection, and in many instances (beyond what can be distinctly ascertained) the result has been most disastrous. It is, therefore, the imperative duty of the architect to devote his earnest attention to this subject; and it is a desideratum with the profession at large to obtain as many facts as possible which may tend to throw light upon it by their practical results. Under this impression I have been led to think that the instance I am about to describe may not be undeserving of the notice of the Institute, and that it may induce others to make contributions of the like nature, which together might constitute an useful mass of information bearing upon the same point.

The subject of Warming the Long Room of the Custom House had excited considerable attention, in consequence of the noxious effects experienced from the apparatus employed since the reconstruction of that part of the building, by which the health of the officers in that department was so seriously affected, as to give rise to repeated and urgent representations to the Commissioners.

After more than two years spent in correspondence and fruitless experiments to remove or alleviate the evils complained of, the assistance of several scientific and practical men was called in, who investigated the causes, and proposed various remedies, and other modes of warming, accompanied by plans and estimates; the result of which was, that the whole matter was submitted to the Lords of the Treasury, and by them referred to Dr. Arnott, who had recently distinguished himself by his works on physical science, and particularly by his admirable Treatise on Warming and Ventilating. The Doctor having fully reported his opinion, recommending the adoption of the principles explained in his work, he was authorized by the Treasury to carry his plans into effect: a task which, although quite out of the line of his proper pursuits, and likely to interfere much with his professional engagements, he was nevertheless induced to undertake, from a desire to avail himself of so favourable an occasion to give a public illustration of his plans upon a grand scale, and thus render their advantages better known and appreciated. As the arrangements necessarily included many practical and architectural considerations, and as much superintendence would be requisite to insure a correct execution of the various details, he did me the honour to request my assistance in these respects.

The means of warming hitherto adopted consisted of six furnaces erected in the cellars, two stories below the long room, to which air was introduced from outside the building; it was then heated by iron cockles, and conveyed into the room through two large cylinders of brickwork, carried a little above the floor, and capped with cast iron plates, the warm air being emitted through open gratings at the sides. As the fires were not kept up at night, it became necessary, in order to raise the temperature sufficiently during the few hours that the stoves were in operation, to produce an excessive heat within this limited period, so as to compensate for the rapid absorption of it by the cold walls and other surrounding materials. To effect this, the air emitted from the stoves was heated to such a degree as to give it all the noxious qualities of a sirocco, to which indeed it was closely assimilated both in cause and effect. The consequences as regards the health of all those within the scope of its influence were fully described in Dr. Ure's report, viz. dryness of skin, coldness of the extremities, headaches, giddiness, &c.; and always a great number of officers were absent on account of illness and incapacity for business. To so great an extent did this prevail, that it was deemed necessary by the Directors of the Customs Mutual Life Assurance Society to interfere for the protection of their interests, which were thus so seriously menaced.

The principle of the stove invented by Dr. Arnott is sufficiently known through the medium of his Treatise to render it unnecessary, on this occasion, to enter into any particular description of it. The distinguishing features and advantages are—self-regulation, by means of a thermometer or pyrostat, and consequently uniform action; extreme economy of fuel; its not being liable to deteriorate the air by warming, as is the case with stoves in general, from the great heat of the surface upon which the air impinges; the stoves being kept in constant operation, and therefore always maintaining an uniform and gentle heat, instead of alternating between two extremes equally injurious; economy of labour or attendance, which for these stoves is usually required only once or twice in twenty-four hours; and in most instances there is also a saving in original cost as compared with the various kinds of stove which have been brought into use, or with the apparatus for warming by hot water or steam.

The long room of the Custom House is 186 feet long by 64 feet wide, and about 44 feet high, which dimensions, after deducting the projection of piers, &c. give a cubic area of about 500,000 feet. There are thirteen windows in front, containing 780 feet of glass, and eighteen borrowed lights in the cove of the ceiling, containing upwards of 1000 feet, besides three windows at each end above the cornice, containing 320 feet of glass. The first measure adopted was to add inner sashes to all the windows excepting those on the ceiling, and thus prevent the principal waste of heat. Then, according to the preceding data, making due allowances for ventilation, Dr. Arnott calculated that the room might be efficiently warmed by three stoves, placed on the floor, in central positions, containing together about 800 feet of surface, by which the heat may be communicated to the air of the room. In ordinary cases the surface consists merely of the enclosure or box of the stove, but when a large extent is required, this mode of producing it would create an inconvenient bulk; therefore, in the present instance, the great extent required is obtained mostly by tubes passing through the cases of the stoves, open at both ends, so that the air may circulate through them, and thus distribute the warmth. This will be described more particularly in the construction of the stoves. It has been always experienced that artificial modes of warming have a tendency to deteriorate the air by depriving it of its due proportion of moisture, which was the principal evil arising from the former apparatus; and although it has been almost wholly avoided in this instance by the low temperature of the heated surface, yet Dr. Arnott thought it prudent to provide against any tendency of this nature by introducing an evaporating apparatus into each of the stoves, which together throw off from seven to eight gallons of water in the course of

twenty-four hours, the quantity varying according to the heat of the stoves, which is governed by the state of the external temperature; besides which, it may be calculated that rather more than the above quantity of water is evaporated by daily sprinkling the floor. The experience of the past season has shown, that by means of these stoves the temperature of this vast room has been maintained at about 58° during the coldest weather; at other times, when the weather was milder, two stoves were found sufficient; and occasionally one only was used. The consumption of each stove varies from two bushels to one bushel of coke in twenty-four hours, so that when worked to the fullest extent, the expense for the long room alone did not exceed six bushels, or about five shillings and threepence per day; which is found to be a saving of about two-thirds as compared with the former mode of warming. The original furnaces were made to serve also for warming the warehouses and cellars underneath, by turning off the stream of hot air from the long room after the hours of business, and the fires being left to burn out, the remaining heat was distributed in the lower stories, the lowest of which had the level of its floor under that of high water; it was consequently damp, notwithstanding the operation of the furnaces, and therefore injurious to the goods deposited there. It was therefore very desirable to remove this evil, and it has been effected by introducing two smaller thermometer stoves into this range of cellars, which embraces the same extent as the long room over, by a height of about 11 feet; and the same has been done in the intervening range of warehouses. It is remarkable, that when only one or two stoves are in operation in the long room, the circulation of the air is so rapid that the heat is equally distributed throughout, so that no difference can be perceived in those parts which are nearest or most remote from the source of heat, and consequently it is a matter of indifference which of the stoves is used or let out when the whole are not required.

The long room encloses, as already stated, about 500,000 cubic feet of air; the time that it is occupied for business is about seven hours each day; and the number of persons, one hundred and thirty officers and clerks, besides the merchants and others resorting thereto, which on an average do not amount to one-fourth of the proportion which a congregation bears to a church, and still less as compared with many other public assemblies of a denser character: considering all these circumstances, it might be inferred that the deterioration of the air would be very trifling, and the ventilation proportionably less important; but ventilation is an essential accompaniment to warming, and it has been carefully provided for in this instance by simple means adapted to the existing

circumstances of construction and locality. In the borrowed lights in the cove of the ceiling there are six small casements, through which when opened the heated air rushes out with great rapidity, in proportion to the heating power of the stoves and the quantity of cold air admitted below, which is introduced under each of the stoves; the two end stoves drawing their supply from apertures cut out under the windows in the front, from whence the cold air passes between the floors and ceiling to valves under the steps, on which the stoves are placed, that can be regulated as required. The central stove is supplied with cold air by ducts opening near the floor of the passage below, which is always open to the quay during the hours of business. Besides these, there is an air shaft at each end in the corridor behind the room, connected with cowls at top, made to turn their mouths to the wind, and at bottom distributing the cold air along the sides of the room, where it is emitted through small apertures underneath the presses. All these air-ducts are furnished with shutters, so as to control the current, and they are regulated and adjusted according to the temperature, the direction of the wind, and other circumstances. In the cellars, the floor of which is below the level of high water, the temperature has been steadily maintained at 57°; and the dampness of the floor, which was before considerable, and very injurious to the goods, has almost entirely disappeared.

With regard to the form and construction of the stoves for the long room, it was Dr. Arnott's desire to render the exemplification of his principle in this instance the more striking and complete, by presenting a variety of modes, in order to show how stoves of this nature may be adapted and applied under various circumstances, both in regard to taste and convenience; consequently the two end stoves are made of a *square* or cubical form, with *descending* flues; and the central one is *circular*, with an *ascending* flue, or tube passing through the roof. Considering the imposing aspect of this vast room in an architectural point of view, it was deemed proper and consistent that the stoves should be rendered suitable in their external appearance to the situation they were to occupy as appendages to so noble an apartment. Upon this principle I prepared the designs now produced, which were submitted to the Honourable Commissioners, and have been carried into effect with scarcely any deviation, adopting such simple forms and arrangements as might be compatible or not interfering with the main purpose to be effected. It must be obvious that in this case, when so great a power was required beyond what had been previously attempted, there would be a necessity for new forms and arrangements, and that no preceding patterns or models could be rendered available; there-

fore, however simple and apparently inexpensive may be the forms and arrangements adopted, a large expense must unavoidably be incurred, simply from their being *original* or expressly made, and in that respect an instance of this kind furnishes no criterion of the expense in ordinary cases.

The result of experience induces me to make this remark, having found it to apply to every part of the process of the manufacture as well as to the execution of the external design, and has shown in a very striking degree how vastly more expensive is every work that does not come within the ordinary course or processes of the manufacture.

The casings or enclosures of the stoves are of plate iron, the thinness of which as compared with castings was desirable for the more ready transmission of the heat; the ornamental parts are of cast iron, and some of those more delicate and enriched are of bronze.

The stoves are raised upon two stone steps, which, besides the advantage in appearance, serve to contain passages for introducing the air underneath through the apertures in the centre of each side; from whence it passes through the heated tubes in the body of the stove, and thus distributes the warmth. By this arrangement a constant and regular circulation of the whole of the air of the room is maintained, so that every part of the same level is found equally warm, whether near to or remote from the stove or source. The upper part of the room next the ceiling is of course proportionably warmer than the lower, as is felt upon approaching the casements or outlets in the ceiling, where the air rushes out with a force sufficient to float a silk handkerchief; and when the aperture was cut through in the centre for the tube flue, the force of the warm air rushing up almost blew off a man's hat. It is by taking advantage of this principle, of the balance of air being destroyed by rarefaction, that the ventilation is effected as before described; and in proportion as cold air is admitted at bottom, so will the heated air be expelled at top, with a force regulated also by the height of the column so acted upon.

To proceed with the construction of the stoves, and first of the square ones, it will be seen by the drawings that each consists of a square case of plate iron riveted at the angles to separate pieces formed for that purpose, and the joint is covered externally by the ornamental pilaster. The top and bottom are united in the same manner, the joints being concealed by the plinth and frieze. With reference to the plate, *figs.* 2 and 3, the case or body of the stove is thus occupied, viz. by the fire-box or furnace *a* in the centre, for generating the heat, surrounded by twenty-two tubes *b*, passing through from bottom to top, whose surfaces, together with the external casing, serve to distribute it by

Fig. 1.

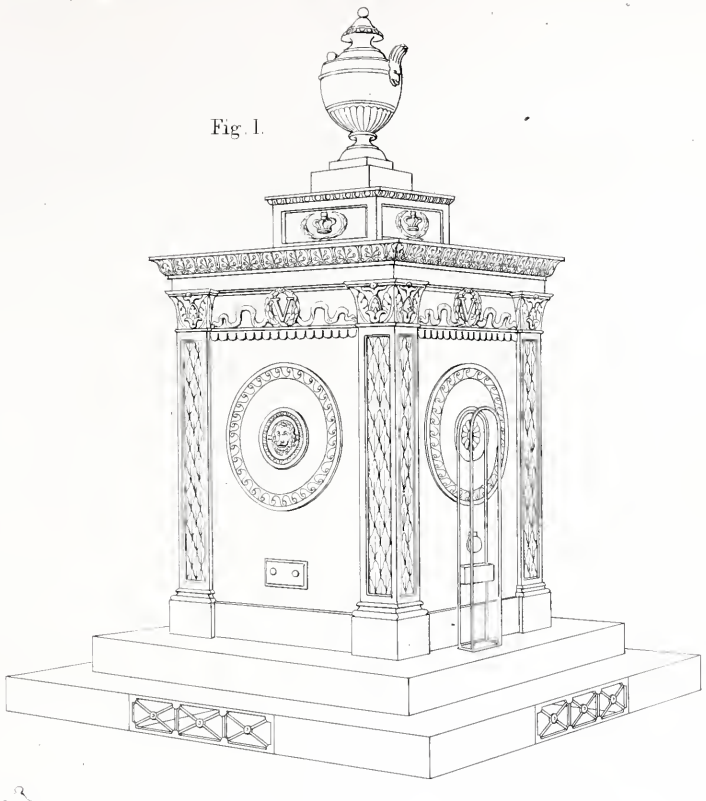


Fig. 2.

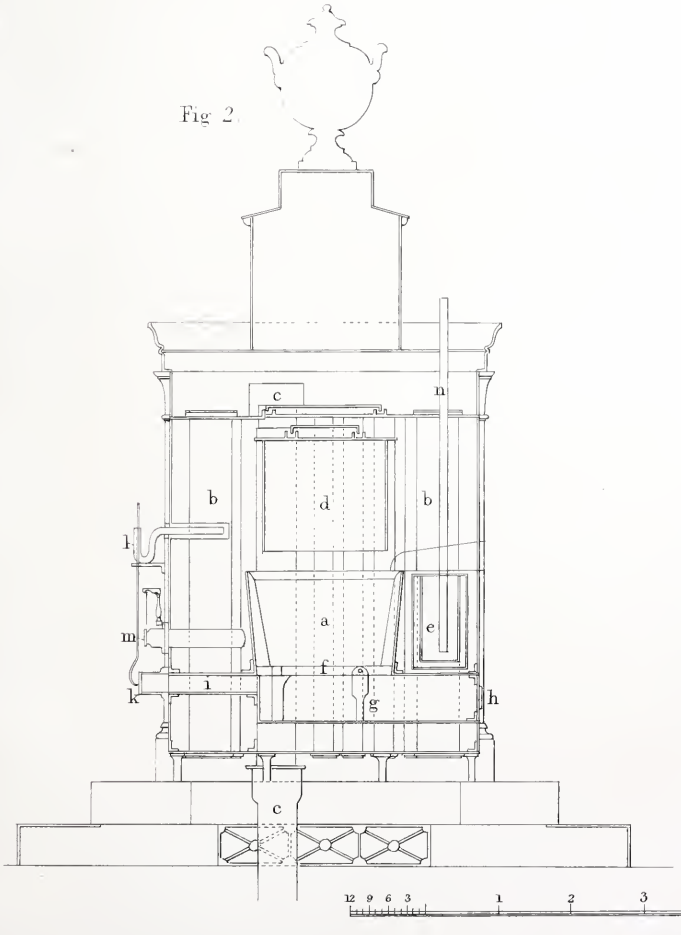
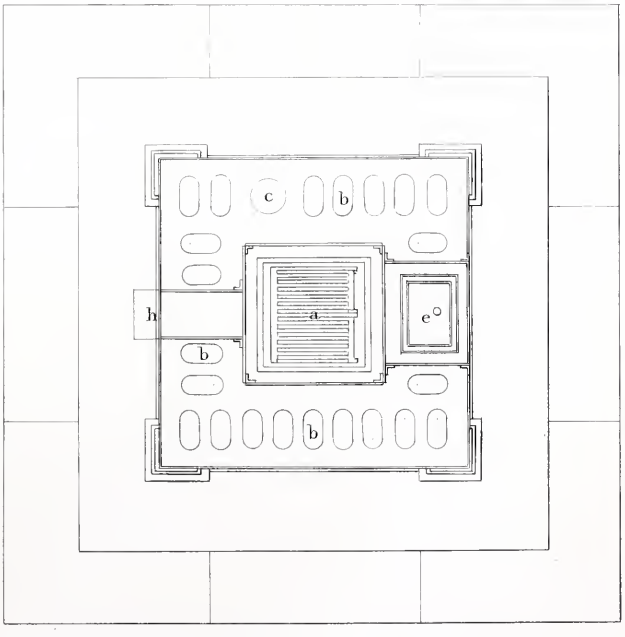


Fig. 3.



C. Fowler. Arch.t. T.T. Bury. sc.

STOVE PLACED NEAR TO EACH END OF THE LONG ROOM OF THE CUSTOM HOUSE-LONDON.

contact with the surrounding air, which circulates through and around the stove by the impulse of the heat; besides which there is the smoke flue *c* descending through the floor, the hopper *d* or receptacle over the furnace for supplying the fuel, and the boiler *e* for evaporation. The tubes are of the form of a compressed or flattened cylinder, in order to admit of a more compact arrangement, and to give a larger proportion of surface than could be obtained from perfect cylinders; and they are rivetted at the top and bottom to a rim attached to each extremity. The furnace consists of a stout wrought-iron box two feet square in width and depth, the top being four inches wider than the bottom. The fire grating *f*, which is six inches above the bottom, consists of two loose frames of bars, supported at one end on a shifting leg, so that each can be let down if necessary to remove any obstruction from clinkers, and without extinguishing the fire. The sides of the fire box are lined with two-inch Stourbridge lumps as non-conductors, to confine the heat and maintain a steady combustion. The ash pit *g* forms a continuation of the bottom of the fire box, and is cast in one piece with it, in order to insure perfect soundness of construction. The greatest attention is requisite in fitting the ash pit door, *h*, so that it may shut quite close, and that no air may be admitted except through the appointed channel under the government of the regulator; for upon this mainly depends the practical efficiency or successful working of the stove. The air which feeds the combustion is introduced through a tube *i* affixed to the back part of the ash pit. The mouth of this air duct is furnished with a valve *k* hung on pivots and nicely balanced, which is moved by the rise and fall of a float in mercury in a glass tube *l* immediately over it. The extremity of this tube being inserted into the stove, the heat to which it is subjected expands the air contained within the back part of it, and the mercury is thus brought to act in exact proportion to the temperature of the stove; so that as the heat increases it closes the valve and checks the fire, and *vice versâ*. This simple and admirable contrivance of self-regulation is exemplified in various ways by the different modes adopted in the other stoves, which will be described in their proper place. It may be remarked, however, in general, that to insure its successful operation it is important to give it free action, by studiously avoiding complexity in the mechanical means adopted; and that the execution of the work should be perfectly accurate; as it must be obvious that where so little power is exerted, if there be any impediments from misadjustment, stiff joints, complicated movements, or any causes of that nature, the valve will not be properly acted upon, and the fire may go out, or, what is much worse, may burn at such an ungovernable rate as to produce great

annoyance if not serious mischief. This has unfortunately happened in some instances among the great number of stoves that have been made *professedly* upon Dr. Arnott's principle, but so defective either in plan or execution as to defeat its objects and destroy its advantages; and sometimes the same disappointment has resulted from mismanagement of servants and others to whose care they have been intrusted. The fuel is supplied from the top through an aperture under the square pedestal (surmounted by the vase), for which purpose the pedestal is made to slide back on the two bearing bars that support it. The lid is rendered air-tight by means of a sand groove; and there is another lid within, which covers the hopper for receiving the coke. This hopper is suspended over the fire box, leaving an interval of about four inches between the top of the one and the bottom of the other, for the escape of the air and gas thrown up by the combustion. The addition of the hopper has been found an important advantage, by preventing the accumulation of gas, which would be liable to explode; and it insures a more steady combustion, as the fire box, being by this means always kept full, the fuel descends upon the fire in a prepared state, by the effect of the heat it has been subjected to. The smoke or gas is carried off by a six-inch iron tube *c* before referred to, and, for greater security from explosion, a small tube is carried into it from the top of the hopper, in order to take off any gas that may be distilled from the mass, in case the fuel should not be of a pure and proper kind. In order further to regulate the draft of the fire through the smoke tube, there is a communication made to it from an aperture in front of the stove *m*, at the mouth of which a valve or flap is suspended; so that if the draft flags, the flap opens and admits air through the tube, which will quicken it; on the contrary, when the draft is brisk, it is checked by its sucking the valve close, so that no air can then pass. This valve is generally found in motion, and serves to indicate plainly the force of the draft. Also the state of the fire is ascertained by opening a small disc, which gives a view into the ash pit. The smoke tube is carried down through the flooring, and continued horizontally underneath, being suspended from the iron beams, until it reaches the back wall, where it enters the ordinary brick flue. The horizontal tube, which is of cast iron, six inches diameter, is enclosed within another of sheet iron nine inches diameter, and the interval stuffed with pounded bricks, in order to retain the heat and promote the draft. Underneath the junction of the horizontal tube with the upright flue in the wall, a receptacle is placed to collect any condensed moisture, which is liable sometimes to accumulate, and might be injurious if not removed. There is a rotary blowing apparatus introduced a little above, in

order to give the first impulse to the draft from the stove, by exhausting the air in the tube below, and thus sucking down the smoke; or it might be used if at any time from accidental causes the draft may be insufficient, but this has not been the case.

It will be seen, by a general view of the internal arrangement, that the body of the stove is entirely exposed to the influence of the fire contained within it, so that the whole of the air is heated and mixed with the gas or smoke given out in the combustion (but of the latter the quantity is exceedingly small if proper non-bituminous fuel be used). The heat thus generated is transmitted to the air of the room through the surfaces of the enclosure together with the tubes (by which the extent is more than doubled), and the heat of the metal being by this means so much diffused and moderated, viz. to about 137°, it is rendered quite free from any deleterious effect on the surrounding air. It is further tempered or moistened by the evaporation from the boiler, which is placed at the side of the fire box, having the tube *n* carried through the top of the stove to give vent to the steam. The weight of each of the square stoves, when charged with coke, is about two tons and a quarter, independent of the stone and brickwork upon which it is raised.

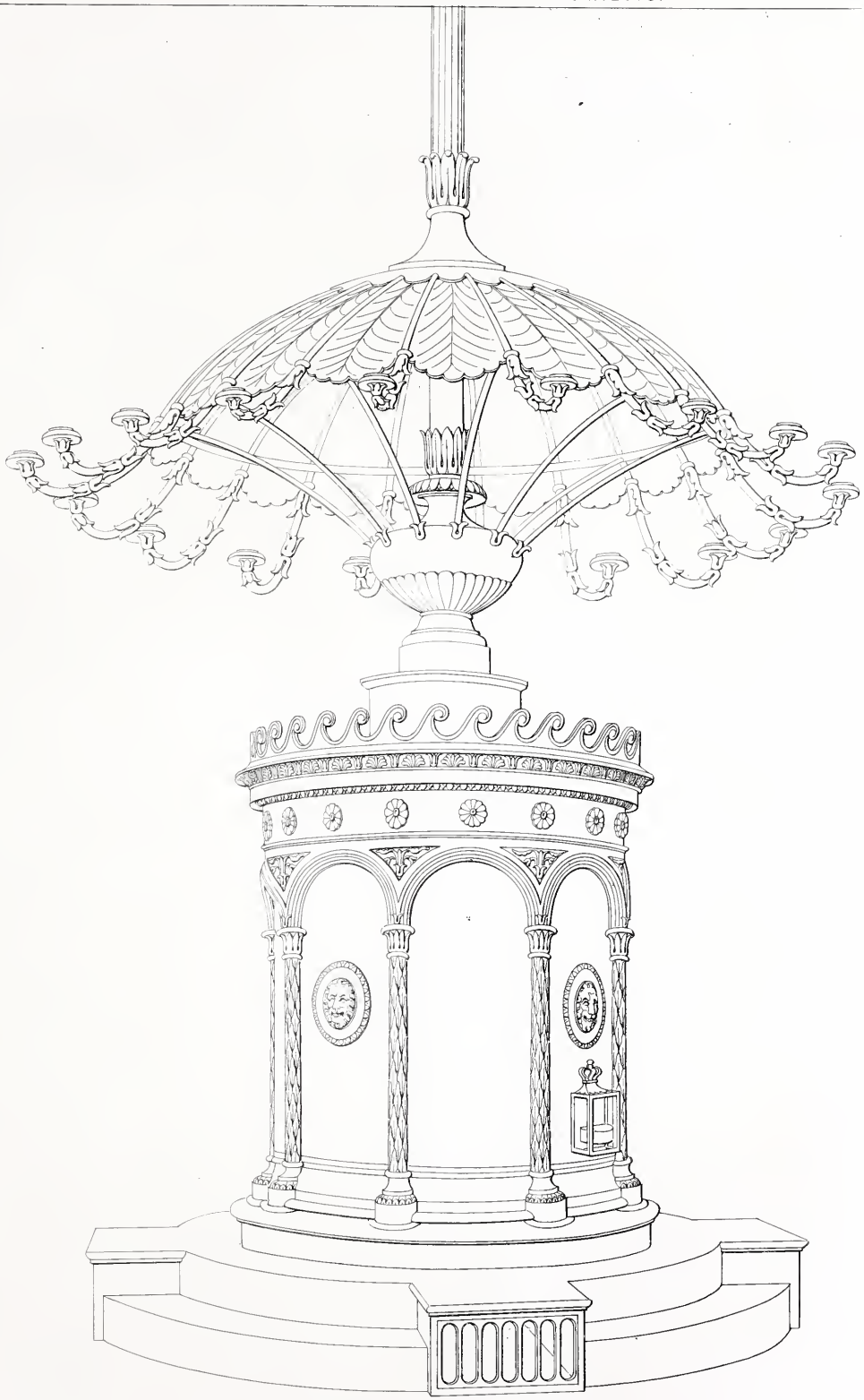
In the corresponding stove at the west end of the room there is this difference: the fire box is continued to nearly the top, and enclosed from the stove by a lid shutting into a sand groove, with a lesser one within it, which is opened to admit the fuel; by this means if there be any gas distilled it is prevented from passing into the general enclosure, but is carried by a small tube at top directly into the chimney or draft tube. The draft from the fire box is carried out near the top by a tube, bent downwards to prevent any escape of gas, and thence finds its way through the enclosure to the top of the chimney tube as in the former case. This stove has also a different regulator, formed of a bar of brass, which by expansion lengthens, and thus gives motion to the valve, consisting of two discs hung together, so that any draft or impulse of air which might tend to disturb their action is counteracted or balanced by having a contrary effect on each, viz. in proportion as one is sucked close the other is opened, and thus an equable and uniform action is maintained.

In the centre stove the arrangements and construction are upon the same principle as those already described, but enclosed in a circular instead of square case. The concentric arrangement of the parts within is more consistent with the uniform distribution of heat, with regard to the fire box and surrounding tubes; and the cylindric form of the fire is preferable to the cube; but it may be questionable whether, in a practical point of view, these advan-

tages are equivalent to the additional expense attending the construction of circular forms, at least in such an instance as the present, where every part had to be prepared originally. If such a form were adopted generally, and were manufactured (according to Mr. Babage's definition of that word) by means of moulds, and patterns, and other mechanical facilities, it is probable that it would not involve any additional expense, and it must be admitted to have the preference for beauty and convenience. The chimney tube from this stove is carried straight up through the roof, and is combined with a spreading canopy just over the stove, so as to give the appearance of a chandelier suspended by a cable. The tube is of copper, reeded, and only 5 inches diameter. The lower part, to the height of about 10 feet, contains an iron tube, to prevent the corrosion which the gas would be liable to produce on the copper in that part being so near the fire. There is also a receptacle at the bottom of the inner tube, to receive the tar which is occasionally distilled and condensed on its surface. All that part of the tube which is above the canopy, comprising a length of about 45 feet, is supported from the roof and ceiling; the remainder, together with the canopy, rests upon the vase, which is of cast iron, supported on bearers across the top of the stove. The canopy is formed with a wrought iron frame, the bearers of copper, and the branches of brass. The canopy is not merely an ornamental appendage, but serves also to detain the heated air arising from the stove, and diffuse more of its influence in the lower part of the room, instead of its being thrown immediately up to the ceiling.

These stoves have been in operation from the beginning of November last during the whole of the winter or cold season, and with the most satisfactory results. During the occasional mild weather only two stoves were required, and sometimes one was sufficient, consuming from about two bushels of coke each in the course of twenty-four hours. The temperature has been maintained very steadily to about 58°, and the air when so warmed was found to be entirely free from the injurious effects so much complained of before; in proof of which, the number of officers absent on account of sickness has been much less than in the three preceding winters. In addition to this the main benefit, there is a saving of about two-thirds of the expense of fuel.

It has been already mentioned that thermometer stoves are introduced into the warehouse and cellar occupying the two stories under the long room. There are two in each story, and another of the same description in an adjoining lobby on the ground floor, forming the principal entrance from Thames Street. The flues are carried into the same chimneys as are used for the square stoves in the long room, and it is found that they tend to assist the



C. Fowler, Arch^t. T. T. Bury. sc.

STOVE IN THE CENTRE OF THE LONG ROOM OF THE CUSTOM HOUSE-LONDON.

draft of the latter. Those minor stoves are of the plainest and cheapest construction, and they fulfil their purpose most satisfactorily. *They* serve, therefore, as examples of efficiency combined with *economy*, which latter object could not be obtained in the execution of those in the long room, where there were many unavoidable circumstances tending to increase the original cost, so that they could not furnish any criterion in that respect.

The Examiner's office, adjoining to the west end of the long room, is also warmed by a thermometer stove, upon the same general principle as those in the warehouses, viz. the extension of the heated surface of the enclosure of the stove by corrugation, and modified in other respects to adapt it to the situation. The whole of these stoves are managed by one attendant, who ordinarily feeds them with coke in the morning and evening, excepting on Sundays, when the warehouses and cellars are locked up, but the stoves are generally found burning on the Monday morning. This duty, together with regulating the ventilation, occupies about half of a man's time, and requires no particular skill, but only ordinary attention and regularity. The coke used is that prepared in ovens, and not from the gas works, as the latter is liable to be imperfectly burnt; and if any considerable quantity of gas be contained, it may become offensive.

I have only further to add, that in making this communication I considered I was following out the wishes and intentions of the talented inventor of the plan, viz. that this occasion might serve to make his principles better known and appreciated, by giving a practical illustration of them upon so grand a scale; and that thus they might be rendered more available and useful to the public.

Being deeply impressed with the sense of their great value and importance, and the benefit that will accrue from their being eventually brought into general use, in regard to health, convenience, and economy, I cannot conclude without offering my humble tribute to the individual who, upon this and other occasions of the like nature, has successfully devoted his time and talents in promoting the public welfare, without any regard to private interest or advantage. Upon these grounds Dr. Arnott is entitled to rank as a public benefactor, and he is eminently deserving of the grateful acknowledgments, not of his countrymen alone, but of the whole civilized community.

CHARLES FOWLER.

Gordon Square, July 13th, 1840.

REPORT ON THE CONSTRUCTION OF A STONE ARCH BETWEEN THE WEST TOWERS OF LINCOLN CATHEDRAL.

BY W. A. NICHOLSON, Architect, Lincoln.

THE construction of the stone arch (or, according to its popular designation, "stone beam") which exists between the western towers of Lincoln Cathedral, having been discussed at a meeting of the Institute when I had the honour to be present, and finding that although it appeared a subject of interest to the members, yet that little accurate information upon it was to be found, I determined to examine it minutely; and I beg to transmit the accompanying drawing of the arch, made from very careful measurement, for the use of the Institute, in case the Council may think it worthy of a place amongst its documents.

The arch is constructed between the western towers, at a height of about eighty feet from the pavement of the cathedral, and immediately over the junction of the vaulting between the towers and the vaulting of the nave; its abutments are thus formed by the eastern walls of the two towers.

The arch itself consists of twenty-three stones of unequal lengths; the width of the extrados is barely 1′ 9″$\frac{3}{4}$; the thickness of the arch is uniform throughout, and is 11 inches. The span, measured horizontally, is exactly 27′ 11″ between its *apparent abutments;* but it is necessary to observe that the towers, which are of Norman construction, have been in several parts encased with new masonry in the interval between their original erection (about 1100) and the completion of the nave, aisles, and other adjacent parts (about 1250) as they now exist. This facing is continued above the arch in question, and the formation of the joints in the new stonework leaves little doubt that the *real abutments* are formed by the original walls of the towers, thus making the actual horizontal span 30′. The southern abutment is 12$\frac{1}{4}$ inches higher than the northern one, measuring upon the new facing just described. The haunches of the arch are filled up as described in the drawing, and there are indications of the filling in having been continued nearer the centre than it is at present. This part of the work has been originally bedded in mortar, but is now quite loose and detached.

In all the authorities I have had an opportunity of consulting, the arch has

STONE ARCH BETWEEN THE WESTERN TOWERS OF LINCOLN CATHEDRAL.

Fig. 1.

ELEVATION LOOKING EAST.

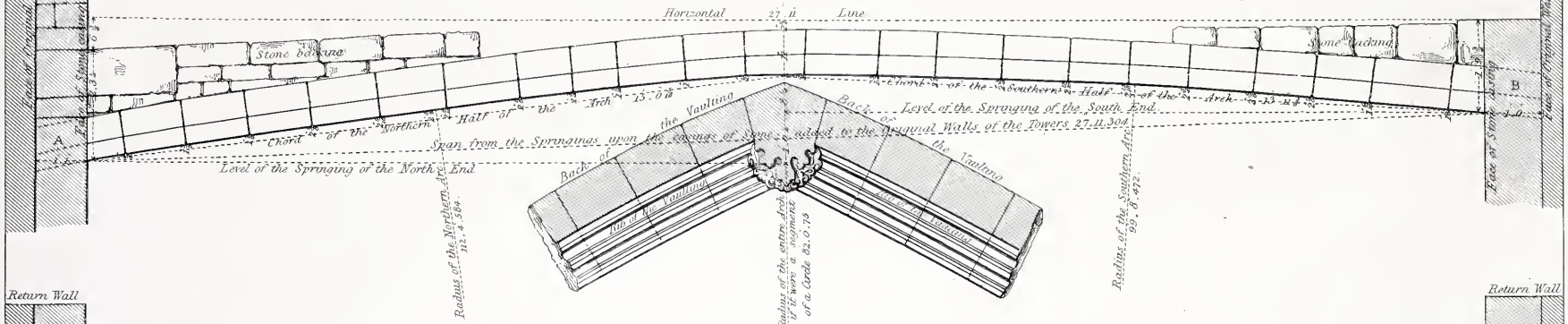

Horizontal 27 ft Line
Face of Original Wall
Stone backing
Stone backing
Chord of the Northern Half of the Arch 15.0.18
Front of the Southern Half of the Arch 15.0.18
Span from the Springings upon the casings of Stone added to the Original Walls of the Towers 27.11.304
Level of the Springing of the North End
Level of the Springing of the South End
Back of the Vaulting
Back of the Vaulting
Face of Stone casing
Radius of the Northern Arch 112. 4.504
Radius of the centre arch if it were a segment of a Circle 82.0.19
Radius of the Southern Arch 99. 8.472
A
B

Fig. 2.

PLAN OF THE ARCH.

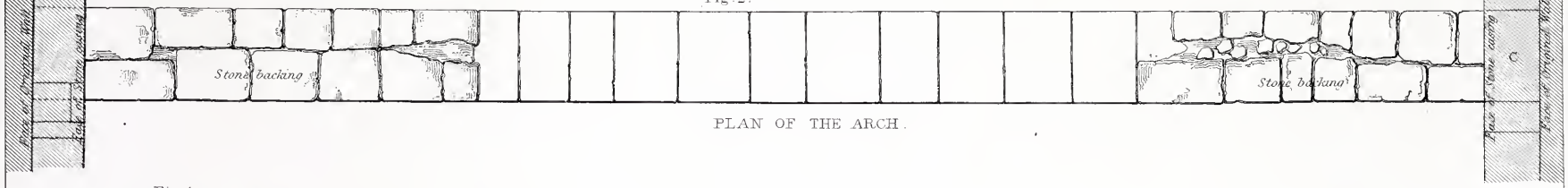
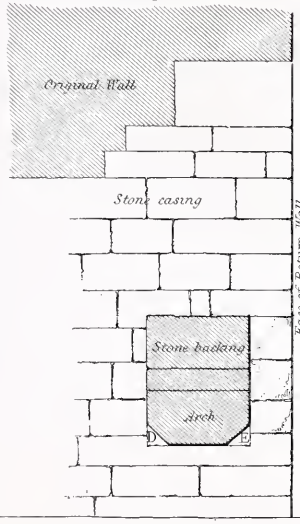


Fig. 4.



SECTION THROUGH NORTH END OF ARCH SHEWING ELEVATION OF STONE CASING.

Scale of Feet

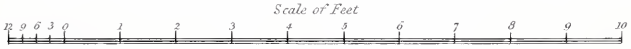
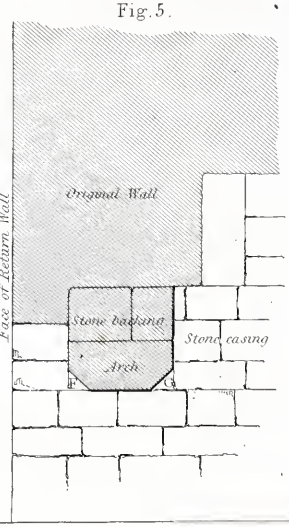


Fig. 3.

SECTION THROUGH CENTRE OF ARCH.

Sketched & Measured by Mr. W. A. Nicholson, Architect, Lincoln. F.R.I.B.A. &c.
& Drawn by Wyatt Papworth

Fig. 5.



SECTION THROUGH SOUTH END OF ARCH SHEWING ELEVATION OF STONE CASING.

T. T. Bury. sc.

been considered a segment of a circle. It is true that in a description of the cathedral drawn up by Mr. Lumby, clerk to the fabric, and published in vol. iii. of Vetusta Monumenta, its deviation from a segment is noticed, but is attributed to a "very small settlement." This, however, is not the case, the dimensions leading to an obvious conclusion that the arch is *pointed*, and described from two centres. In order, nevertheless, to afford an opportunity of comparing the conclusions deduced by other parties, who have given the dimensions of the arch, upon the supposition of its being a segment, with those which would follow from the admeasurements I have made, it may be well for the time so to view it. Thus considered, its chord would be found by calculation to be 27′ 11″·304; the versed sine of half the arc 1′ 2″·375 and consequently the radius would be 82′ 0″·75, and the arc would include 19° 36′ 16″.

But, as I have just said, minute admeasurements preclude the supposition of the arch being a segment of a circle; for had such been the case, every part of the arc would have conformed to the same law, and an investigation founded on the dimensions of any portion of the arc would have resulted in showing the same radius. On drawing the elevation from the dimensions, and whilst I was still impressed with the popular idea that the arch was a segment of a circle, it became obvious to the eye that it was of a pointed form; and on testing this by calculations based upon the dimensions, I found this minutely verified. The drawing has been made by describing each arc with a radius of a length calculated from the dimensions, and given hereafter; the actual position of the soffit of each stone, wherever it deviates from the line described by the assumed arc, is marked by a red line on the elevation, and it will be perceived that with trifling exceptions, and those obviously the result of some derangement in the original form of the arch, it coincides most accurately.

On examining the southern half of the arch, it will be seen that the length of the chord line is 13′ 11″$\frac{5}{8}$ as measured (or more accurately 13′ 11″·664 as determined by calculation); the versed sine of half the arc is 2″$\frac{15}{16}$, from which it would follow that the length of the radius would be 99′ 8″·472, and the arc would comprehend 8° 2′ 8″.

The length of the chord line of the northern half of the arch is 14′ 0″$\frac{5}{16}$ as measured (more accurately 14′ 0″·324 by calculation), the versed sine of half the arc is 2″$\frac{5}{8}$, which will give the length of the radius of this side 112′ 4″·584, and the number of degrees included in the arc 7° 10′ 4″.

It will be perceived from the above notes that the radius of the southern arc as deduced from the dimensions is about 12′ 6″ less than that of the north arc; and the versed sine of half the arc $\frac{5}{16}$″ greater. This inequality is perhaps the result of irregular settlement when the arch was first built, or more probably

of some subsequent yielding of the abutments, as both the towers have many extensive fissures in them, which could scarcely occur without some derangement of the form of the arch. Indeed there is reason to believe that since the publication in 1791 of Mr. Lumby's report before referred to, a spreading of the abutments has occurred. He describes the soffit of the arch as being 12 inches above the stone vaulting, whilst at this time it is not more than 3 inches. His investigations appear to have been conducted with great care and accuracy, and it is difficult to believe he could commit so great an error in nearly the only dimension that can be obtained without the erection of scaffolding.

I may here observe that the dimensions were taken from a central line marked upon the extrados of the arch, which does not coincide with any joint of the stones composing it. Had I been aware when I made the measurement that the result would prove it to be a pointed arch, I should have tested the arcs from the joints nearest the centre; but I trust the results I have obtained are so very near the truth as to justify me in not having scaffolding again erected for other measurements, which could have given very little farther illustration of the fact.

The arch is constructed of stone from the Lincoln quarries, being the same as that used, with few exceptions, throughout the cathedral. The exposed surfaces are wrought with the toothed chisel in a careless and imperfect manner, and the joints, contrary to what might have been expected, are decidedly ill formed, and have beds of mortar fully half an inch in thickness within them. There is no trace of iron being used in the construction of the arch, either in dowels or other form; nor do I believe that it derives assistance from any such extraneous means. The arch vibrates perceptibly when jumped upon, and I am of opinion that the constant practice of visitors thus to prove its elastic properties has a tendency to impair its stability. The mortar between the joints is of a very friable nature, and has detached itself from the parts where it has been used in pointing the joints to conceal the irregularity of the workmanship, and it must be still farther crushed by the violent concussions to which the arch is almost daily exposed.

It appears to me to be in vain to offer any plausible conjecture as to the purpose for which the arch was originally constructed. It is nearly certain that it as not built at the same time that the towers were erected, inasmuch as it would, in that case, have been above the eaves of the original roof; it was more probably built shortly after the reconstruction of the nave of the cathedral, when, for the first time, it was vaulted; but what purpose could it then answer? the vaulting between the towers would have a tendency to prevent any inclination of the towers towards each other of infinitely greater efficacy than the arch

itself; and indeed its form and want of mass preclude the idea of its being built with such an object, at a period when the science of construction was so perfectly understood, and so admirably applied as it was in other parts of the cathedral. It may, as has been generally supposed, have been constructed as a test whether the towers were capable of sustaining the additional height of about sixty feet, besides spires of timber covered with lead, which were superadded to the original Norman towers about the middle of the fourteenth century. But, before such an opinion be received, it must be borne in mind that the vaulting already executed offered a similar standard, and also that the same divergence from the perpendicular which would be indicated by the settlement of the arch, would very probably have occasioned its fall, and the destruction of the vaulting beneath it; and farther, it is obvious that more accurate and less hazardous tests might have been applied with greater facility. On the whole, I cannot avoid thinking that it was not erected with any view of adding to the stability of the towers or of indicating any failure, but rather that it was built by a body of masons desirous of illustrating the amazing effects which the science they studied and practised placed within their attainment.

Reference to the Drawing.

Fig. 1, Elevation of the west side of the arch, and sections through the casing of masonry, A and B, built against the original walls of the towers. It also shows the position of the arch with reference to the stone vaulting between the towers. The dotted lines at A and B indicate the *supposed* continuation of the arch through the masonry of the casing up to the towers. The red lines on portions of the soffit of the arch show the actual positions of the stones composing the arch where they differ from an arc described by the calculated radii.

Fig. 2, Plan of the extrados of the arch. At the south abutment, the backing at C is *seen* to extend up to the original wall of the south tower.

Fig. 4 is a section through the northern springing of the arch, and the backing upon it; it shows likewise an elevation of the stone casing of the north tower, the joints being drawn from admeasurement. The angles at D and E, where the chamfers of the lower edges of the arch intersect the stone casing, are filled in with mortar.

Fig. 5 is a similar section through the south springing of the arch. It will be seen, in the elevation of the stone facing in this figure, that immediately over the arch it is level with the backing in of the spandrel; and thus the backing is exposed as far as the original wall of the tower, as before noted. The angles F and G are filled in with mortar, the same as in the north abutment.

A SUGGESTION REFERRING TO THE STONE ARCH AT LINCOLN CATHEDRAL.

By J. B. PAPWORTH, Architect.

BY the very careful investigation of Mr. Nicholson, he has proved that the stone beam in question was not built for a permanently useful object; in fact he shows that it never did, and of course does not now, add stability to the edifice; and by doing this he has cleared the way most admirably for future investigators.

Not supposing that it was an experiment, nor a demonstration merely of their art by the builders of the time, and admitting its uselessness as a part of the building, it does not follow that it never was of any use at any time. We have neither right nor reason to abandon the enlightened workmen of former ages to the suspicion of erecting works without an adequate demand, and in this instance of the stone arch perhaps they have shown the powers of their minds as fully as though it had been discovered to be greatly useful for strength, or decorative to the edifice. But it often happens that, in our search after truth, we perplex ourselves by seeking for causes that never had existence; perhaps this has been the case for some centuries respecting the stone beam, and the following speculation may prove to be another example.

It may be quite as correct as convenient to place the date of the arch at some time after the completion of the roof and before the building of the vaulting of the nave. Following the practice of workmen in those and other days, we find the centres of the vaultings in progress, a scaffold erected by which to fix them in their places, and the chief workman preparing means for controling and testing the accuracy of the levels, and particularly of the groining points of every arch and groin, along the whole length of the nave. In fact he is seeking to establish a point whereon he may produce at pleasure an imaginary but true line for fixing the crowns of his centres accurately, and for correcting any change of level position that may occur from those powerful causes which operate towards disarrangement in such stupendous works; and being experienced, he

would endeavour so to fix this base that it should be permanent until the completion of all the works, and for after examination.

For this purpose he has resolved to throw an arch from tower to tower—a large span, he says, but no matter, its abutments are adequate, and if it be made so flat as to bear wedging up tightly at the joints, it will be as of one stone, and useable in a week.

This is the arch in question; well arranged to support water or pendant levels, both instruments of early date, at three or four feet above the centring, a height perfectly convenient for use, and obstructing none of the builder's operations.

A SUMMARY OF THE PAPERS

READ AT THE ORDINARY GENERAL MEETINGS OF THE INSTITUTE DURING THE SESSION 1840-41.

1840.

December 7.

On the Characteristics of the Gothique Flamboyant. By Professor Willis, Hon. Mem.

See page 81.

December 21.

Description of the Tower of Antwerp Cathedral. By M. Serrure. Communicated by T. L. Donaldson, Fellow.

The foundation of the Tower of Antwerp Cathedral was commenced between the years 1420 and 1423, and it was completed in 1518. The name of the architect who conceived the plan of this immense work is uncertain, although the probability is in favour of Amelius (Appelman). The total height from the floor of the church to the vane on the summit is 403 feet 7·245 inches English. The restorations, begun in 1827, under the superintendence of M. Bourla, were suspended after the revolution of 1830, but have continued without interruption since 1833. The expense incurred from 1827 to 1838 amounted to the sum of 4,960*l.* 10*s.* and a further sum of 4000*l.* has been estimated as necessary to complete the undertaking.

Observations on Gothic Vaulting. By B. Ferrey, Fellow.

These observations applied principally to waggon-headed Vaults, and more especially to those examples in which the structure of the stone arch forms both the internal and external roof. Abbotsbury Chapel exhibits a remarkable specimen of roofs of this class, the vault being constructed with more than common solidity and skill; and it consequently remains in a high state of preservation, although peculiarly exposed to the elements on the cliffs of Dorsetshire, and long left to neglect.

1841.

January 11.

A Comparison of Norman and Italian Campanili. By E. I'Anson, Fellow.

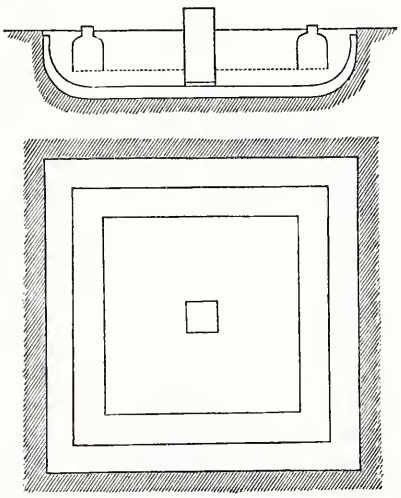
A discourse on the Romanesque Architecture of Italy, and the derivative Norman style, illustrated by examples drawn more especially from Campanili, as affording many close parallels both in composition and detail.

January 25.

Description of the Cisterns constructed for Filtering Rain Water at Venice. By C. Parker, Fellow.

The soil of Venice, as is well known, produces no fresh water. Where wells have been dug, they have always been tainted with a saline or brackish flavour, and water is supplied to the inhabitants partly from the opposite coast, from whence it is brought in boats built for the purpose, and partly from the rain, which is collected and purified in subterranean tanks. These reservoirs occupy a space of about seventy feet square, and are from eight to ten feet deep. The bottom of the pit, which inclines toward the centre, is first intersected with tile or brick drains, the spaces between which are filled with loose stones, and the top covered with the same until the whole bottom of the excavation is made level. The object of this drainage is to catch any water from the sandy veins of the soil, and thus keep the bottom of the tank dry.

This bed of loose rock work is then covered three feet thick, and the sides of the pit puddled, with well tempered clay. In the centre of the reservoir thus formed is laid a large flat stone, slightly hollowed in the middle, to collect any deposit from the water, upon which is raised in brickwork the *canna*, or well from which the water is drawn, rising to the height of three feet above ground. The reservoir all round the *canna* is next filled with sand to the depth of four feet, upon which is laid a drain five feet wide, which runs entirely round the reservoir between the clay sides and the well, and is arched immediately under the surface of the ground. The whole is then filled to the top with sand and paved over, leaving apertures with iron gratings in the top of the drain to collect the water, which thence percolates through the sand, and is raised in the state of clear palatable drinking water from the well.



Description of an Artesian Well sunk at the Surrey County Lunatic Asylum, at Springfield, in the Parish of Wandsworth. By S. Lapidge, Associate.

This well was bored to the depth of 347 feet through the following strata:—

	Feet.	In.
Yellow clay intermixed with veins of sand to the depth of .	30	0
London blue clay interspersed with large clay stones . .	211	0
Clay, shells, and sand, in which was a weak spring . . .	6	6

	Feet.	In.
Dark sand	4	0
Shelly rock	5	0
Brown sand	1	6
Sand and clay	2	0
Mottled potter's clay	4	0
Sand and clay	2	0
Dark sand and shells	5	0
Pure light-coloured sand	1	0
Dark sand	2	0
Sand and clay	1	0
Pink and yellow mottled clay	4	0
Light brown and white clay	4	0
Dark red and white clay	4	0
Dark blue and white clay	4	0
Chalk and pebbles	1	0
Green sand	3	0
Variegated green and brown sand	6	0
Green sand	4	0
Brown sand, wherein was water, which rose to within 36 feet of the surface	5	0
Fine dark gray sand	33	0
Sand and pebbles, from which the water rose to within 28 feet of the surface	2	0
A hard stratum, uncertain	0	6
Chalk	1	6
Flints	4	0
	347	0

February 8.

On the Stone Beam in Lincoln Cathedral. By W. A. Nicholson, Fellow.

See page 180.

On the Construction of Observatories. By A. Poynter, Fellow.

In the construction of buildings devoted to the purpose of astronomical observation, the most important requisite is to provide against the effects of vibration on the apparatus. Any contact with the floor or other portion of the building would not fail to produce, upon the slightest movement, concussions which, multiplied by the magnifying power, would render the telescopes useless. The mode of adapting the building for its peculiar use, is by rendering it independent in all its parts of the piers upon which the instruments are fixed. The foundations of the latter are also laid as deep as possible, in order to obviate the effects of vibration from external causes, against which, however, it is not always practicable to guard, the mere tread of a foot-passenger being often sensible to an observer using a powerful telescope, at a considerable distance.

February 22.

Observations on the Pyramids of Gizeh. By J. J. Scoles, Fellow.

A review of the splendid work on the Pyramids, published and presented to the Institute by Colonel Howard Vyse.

March 8.

On the Architectural Antiquities of Wisby, in the Island of Gothland. By John White, Esq.

The extensive remains of Gothic Architecture at Wisby, a place which in the tenth and eleventh centuries ranked among the most important commercial cities in Europe, have been noticed in Laing's Tour in Sweden. There are at Wisby the ruins of eleven churches, the foundation of which, as shown by documentary evidence, may be dated from 1030 to 1190. Supposing the existing remains to be those of the original buildings, some of them will display examples of the pointed arch and other characteristics of the Gothic style at an earlier period than can be assigned to them in any other part of Europe, and the term *Gothic* may be entitled to a more authentic derivation than is usually attributed to it.

March 22.

A Discourse on the Electrotype. By Mr. Bachhoffner.

An experimental lecture on the Electrotype process, with an especial view to its applicability to architectural purposes, in the production of decorations in metal.

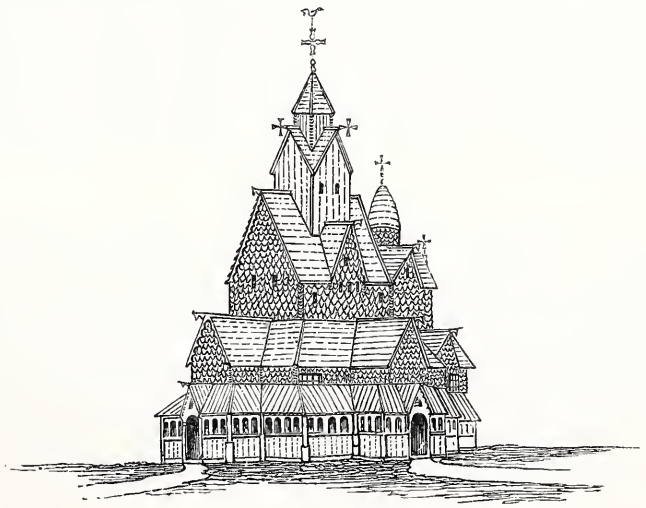
April 19.

On the State of Windsor Castle previously to the Fourteenth Century. By A. Poynter, Fellow.

The materials of this paper, drawn from the Liberate Rolls and other original authorities, are embodied in the historical essay prefixed to the illustrations of Windsor Castle, by Sir Jeffrey Wyatville, published by his executors.

On the Churches of Sweden. By John White, Esq.

A supplement to the paper on the architecture of Wisby, adducing the authority of Torfæus and other historians, as to the flourishing state of architecture in Sweden at a remote period. Among the illustrations to these papers was exhibited the following representation of a church constructed with timber, a remarkable specimen of a style of architecture arising from the properties of the material employed. Other examples may be found in Dahl's "Essay on the Early Timber Buildings of Norway," published at Dresden.



May 17.

On the Connexion of Geology with Architecture, and the Structure and Quality of Stone for Building. By Mr. G. F. Richardson.

June 7.

On the ancient Temples of Greece and Rome. By the Rev. R. Burgess.

A general view of the edifices consecrated by the ancients to the worship of the gods, their nomenclature, forms, parts, and uses—tracing their origin from the statue on a pedestal protected from the weather by the *nimbus* (afterwards a distinctive mark of Divinity, and adopted as a radiant emblem of glory by the Christians)—following their progress in the inclosure of the cella, the addition of the portico, and the gradual improvements which one age made upon another, down to the most perfect structures of Greek art, and the most sumptuous of imperial Rome —commenting on the words used by classical authors to designate the various descriptions of sacred edifices, and the different kinds of porticoes to which the Vitruvian terms are applicable —and describing some of the most celebrated temples of antiquity with reference to the philosophy of their architecture, as shown in the taste and propriety with which their style is adjusted.

June 21.

Report by M. Vaudoyer, Hon. and Corresponding Member, on the Alexandrine Column at St. Petersburgh. Communicated by T. L. Donaldson, Fellow.

This monument was raised on the Place du Palais d'Hiver at St. Petersburg, by the Emperor Nicholas I. to perpetuate the memory of his brother and predecessor, Alexander I. The architect, M. de Montferrand, has adopted the character and proportions of the Trajan and Antonine columns at Rome, but despairing of being able to reproduce the sublimity of the sculptures of those works, he has compensated for the deficiency of sculptural richness by a monolithic shaft of polished red granite eighty-four feet in height. The pedestal, which is also composed of a single block of granite (of a different colour), is enriched on the four sides with bronze bas reliefs; and the whole is surmounted by an allegorical figure, in gilt bronze, of an angel bearing a cross and trampling on a serpent—the work of Orloroski, a pupil of Thorwaldsen.

The project for this monument was presented to the emperor in 1829, and the construction of the work above the foundation was commenced in the year 1831. Its inauguration took place on the 30th August, 1834, being the anniversary of the fête of St. Alexander, when the emperor conferred on the architect the order of St. Vladimir, and awarded him the sum of 5000*l.* and a pension of 240*l.*

On the Timber Roofs of the Middle Ages. By Mr. T. Morris.

The large spans covered by the timber frames of the Middle Ages will readily account for their frequent use in preference to stone vaults, to which they are, however, for the most part analogous in construction, inasmuch as their principle is that of the arch. Various modes of distributing the pressure may be observed in these roofs. In one class the main support consists of a simple arched rib, as in the guard-room at Lambeth Palace. In a second, a portion of the weight is suspended from the main arch by auxiliary timbers; as at Westminster. In a third class, as at Hampton Court, the arch is supported on brackets. In a fourth class the principle

of the arch is given up, as at Crosby Hall, where the roof is formed of two triangular frames, and the tendency to thrust outwards counteracted by the longitudinal strain upon the connecting beams.

July 5.

On the Mechanical Construction of the Vaults of the Middle Ages. By Professor Willis, Hon. Mem.

See page 1.

July 17.

On Iron Roofs, showing their comparative Expense, Durability, and Strength, as contrasted with Timber Roofs. By Mr. E. Hall.

The prize essay, to which was awarded the medal of the Institute.

THE END.

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